REPORTS OF THE
DEPARTMENT OF CONSERVATION AND DEVELOPMENT

Division of Geology and Waters
HENRY B. KÜMMEL, State Geologist

The Quaternary Formations of Southern New Jersey

BY
ROLLIN D. SALISBURY
AND
GEORGE N. KNAPP

Vol. VIII of the Final Report Series of the State Geologist

TRENTON, N. J.
MACCRELLISH & QUIGLEY CO., STATE PRINTERS.
1917.

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CHAPTER I.

INTRODUCTION.

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THE UNDERLYING CRETACEOUS AND TERTIARY FORMATIONS.

The southern part of New Jersey south of the area where the Newark series[2] comes to the surface is underlain by a succession of formations of Cretaceous and Tertiary age which dip

[1] The field work on which this report is based was completed in 1903. The reconnaissance work was done by the senior author, but most of the detailed work was done by Mr. Knapp. Other duties kept him from putting the results of his field studies into written form until long after the field work was completed. This report was prepared by the senior author chiefly from Mr. Knapp's notes. The manuscript was completed in 1912. Various reasons have caused delay in its publication. Preliminary reports regarding these studies were, however, published in successive annual reports of the State Geologist while the field work was in progress. The distribution of the formations has been shown on the Geologic Map of the State, 1910–1912, and also in part in several of the folios of the Geologic Atlas, already published.

For most of the details cited in this report, Mr. Knapp is responsible. Not more than a small portion of the detailed facts which he gathered is here presented. Only those who have tried to unravel the history recorded in such doubtful terms, as in the surface sands and gravels of this region, can appreciate the painstaking effort devoted by Mr. Knapp to the study.—R. D. S.

[2] In general the southeastern limit of the Newark rocks follows closely the main line of the Pennsylvania Railroad, between Trenton and New Brunswick.

30 to 40 feet per mile to the southeastward. Because of this dip, the several formations strike northeast and southwest, and come to the surface in succession southeast of the outcrop of the Newark series. The belt where the Cretaceous outcrops, has a width ranging from about 10 miles to about 25 miles. The southeastern border of the belt runs roughly from Salem near the Delaware, to the Atlantic coast near Long Branch.

Formations of Eocene and Miocene age overlie the Cretaceous system, their dip being much the same as that of the older system. Their outcrops continue, in some measure, the belting of the surface occasioned by the outcrop of the successive formations of the Cretaceous system.

Above the beds definitely correlated with the Miocene, there is another pre-Quaternary formation, or perhaps two formations, dipping somewhat regularly to the southeast much as the underlying beds do. This formation (or the older of the two if there be two) is the *Cohansey sand*, the age of which has not been definitely determined; but it is probably late Miocene or Pliocene. In some places, the Cohansey sand is overlain by gravel, which has been called, in various annual Reports of the Survey, the *Beacon Hill gravel*. Whether it is to be regarded as the upper part of the Cohansey formation, or as a separate formation, is an open question. The gravel is perhaps the equivalent of the Lafayette formation farther south, though this is not demonstrated, and is very subordinate in volume to the sand.

THE QUATERNARY FORMATIONS.

General Statement.—The belted character of the surface due to the successive outcrops of the Cretaceous and Tertiary beds, is much obscured by the discontinuous mantle of post-Tertiary or Quaternary gravel and sand which overlies Cretaceous and Tertiary alike. In places, and for considerable areas, this mantle conceals all older beds; but in other areas it is so discontinuous, because of erosion, that the underlying formations are readily seen. This superficial mantle of gravel and sand of Quaternary age corresponds, in a general way, with the surface formations

of the Coastal Plain farther south, which were described formerly under the omnibus name *Columbia formation.* These beds really constitute a *series,* rather than a single *formation,* and the term *Columbia* will be used here to cover the series as a whole, separate names being applied to its several principal members. The divisions of the Quaternary here recognized are three in number. In order of age, they are (1) the *Bridgeton* formation, (2) the *Pensauken* formation, and (3) the *Cape May* formation.

Origin.—Various views concerning the origin of these formations have been held by those who have studied them, and this diversity of interpretation still exists. (1) Some have thought them to be of marine origin, and to represent successive submergences of the southern part of the State up to heights marked by their upper limits, the several submergences being separated by emergences. (2) Others have thought the several formations to be of subaërial origin, that is, deposited on land, chiefly by running water. (3) Still others have thought the formations in question to be partly of subaërial, and partly of marine or estuarine origin. Within the last view, opinion has varied as to the proportion of the series to be assigned to the one origin or to the other. The third view is the one here favored, with emphasis on the subaërial, rather than on the marine or estuarine mode of origin.

The broad question of subaërial accumulation of sediment is one which, until recently, was neglected; but within the last decade or two, recognition of its importance has become general. Deposition of sediments on land is now in progress at the bases of most slopes, and about most high lands, and it is not easy to see how similar results can have failed of realization under similar conditions of climate and topography, at any time in the past. Deposition is effected not merely by rivers which lead from mountains to plains, but by the run-off of every shower which descends from one slope to another of lesser grade or to a flat. The effectiveness of the process and the extent to which sediments may be spread over the surface where conditions are favorable, is best shown on the plains at the bases of mountains.

Thus the Great Plains at the east base of the Rocky Mountains are more or less generally covered with gravel for scores of miles—in places more than 100 miles—from the mountains. The surface about an isolated mountain is, in some cases, so strewn with debris from the mountain, that nothing but this debris is visible at the surface for miles about it. The plains east of the Andes and south of the Himalayas afford good illustrations of subaërial deposition on a large scale, if the phenomena of these regions have been interpreted correctly.

Perhaps no region affords more striking illustrations of pluvial and fluvial sedimentation than the Great Basin region of the United States. The steepness of the slopes of the Basin Ranges of mountains, the flatness of their surroundings, the relative freedom of their slopes from vegetation, the great changes of temperature which disrupt the rock, and the fitful nature of the precipitation, all contribute to this end. The result is that the plains about and between the mountains are covered, many of them deeply covered, by the debris washed out from the mountains. At the immediate bases of the mountains these accumulations are said to be, in exceptional cases, more than a thousand feet deep. Their depth decreases with increase of distance from the mountains, but is very considerable even scores of miles away in some cases. The Coastal Plain deposits under consideration have many features in common with the deposits at the bases of mountains, though they are on a much smaller scale.

The principles involved.—The essential principles involved in the development of the Quaternary formations of the Coastal Plain, according to the interpretation here favored, are perhaps best understood by a few simple illustrations.

Let us suppose a plain, recently covered by a formation of sand and gravel, to be brought into such a position as to be subject to effective erosion. This might be brought about in various ways, as by the relative uplift of the region which had been the site of deposition. Let it be supposed that a vigorous master stream runs along the lower side of the area, and that tributaries to this stream descend across the plain, at right angles

to their main. Let it be supposed, further, that the main stream reaches such a stage of advancement that it has a wide valley plain at grade. The result is illustrated by Fig. 1, where CD represents a valley plain of degradation, sloping gently toward the master stream. On the upland, A to B, the original gravel formation 1 remains, but its decomposable materials suffer decay by oxidation, carbonation, hydration, etc. Under these circumstances, the plain CD will be strewn with more or less debris derived from the formations 1 and x, but the debris will consist chiefly of the more resistant parts of these formations. Thus if formation 1 contains soft pieces of shale, or pieces of decayed granite, they will not be likely to reappear in the debris

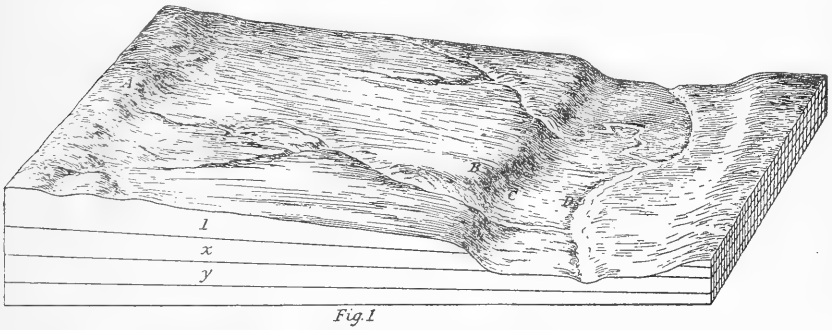


Fig. 1

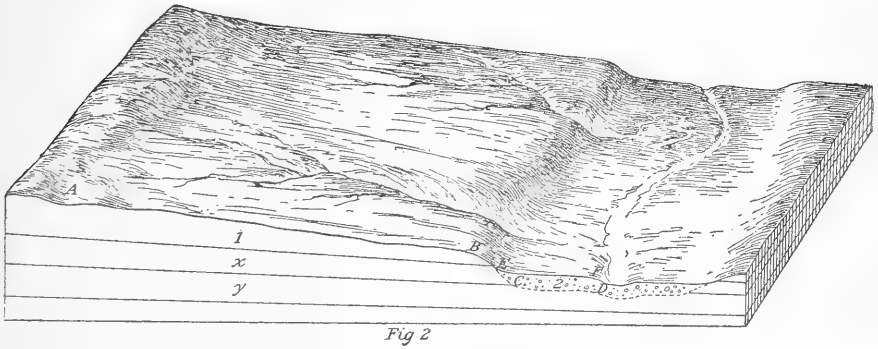


Fig 2

on CD, unless in close proximity to outcrop of 1. At the same time, the material of the lower plain will contain some detritus from x. The result is that the debris on CD may be distinctly unlike the material of formation 1. If the slope between B and

C is gentle, it, too, will be strewn with more or less debris in transit from the higher to the lower plain.

If now the conditions of the region are so changed that considerable deposition takes place on the plain of degradation, CD, we shall have the result shown in Fig. 2, where CD has been aggraded to EF. The material deposited in the valley will be designated formation 2. If the materials of formation 2 were derived from the same sources as those of formation 1, and deposited under similar conditions, they will be similar to them both physically and lithologically, but more or less unlike the slope detritus between B and C. The aggradation of the main valley to the level EF will be accompanied by the aggradation of all the side valleys, but the debris deposited in them may be somewhat unlike that in the main valley, because derived from more restricted sources, namely from the drainage basins of the tributary streams. These streams may have made some contribution to the deposits in the main valley, but a part of the deposits in that valley were brought in by the main stream. While the valleys are being aggraded, waste from the slopes above the valley bottoms may be accumulating on the surface between the two plains (BE), wherever the gradient is sufficiently gentle.

If erosion succeeds deposition, a new flat lower than EF will in time be developed along the main stream, and harmonious flats along its tributaries. Let it be supposed that these new flats are developed at levels lower than those which preceded. The result is illustrated by Fig. 3. On the plain GH, and on the slope IG where it is gentle, there will be slight accumulations of material, deposited as was that on the plain CD, and the slope BC (Fig. 1) at an earlier time. In constitution, the materials on the slope above G (Fig. 3), will be like those on the older and higher slope BE, except that the formation y may have made some contribution to the former. Meantime there has been more or less shifting of the surface material between B and E. The old has been carried on, and new has been washed down from above and deposited, so that the detritus on this slope (BE) is of all ages younger than that of formation 1, dating its age from the time of its depositions.

If conditions now change so that deposition again succeeds erosion, the flat GH (Fig. 3) will be aggraded, as shown in Fig. 4, giving rise to formation 3. At the same time that the main stream is aggrading its plain, its tributaries are of necessity aggrading theirs, but with material of a different sort, if the tributaries drain terranes different from those drained by the main stream.

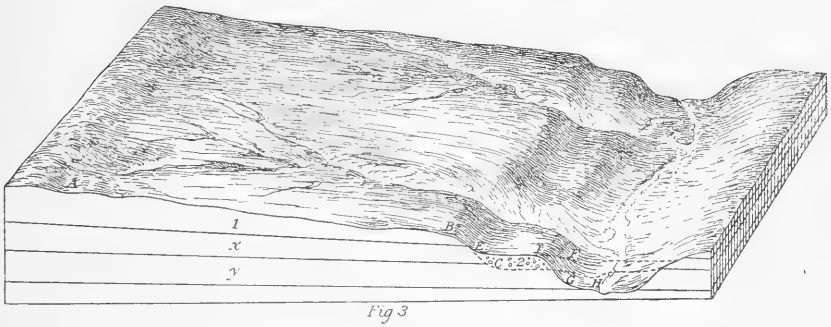


Fig 3

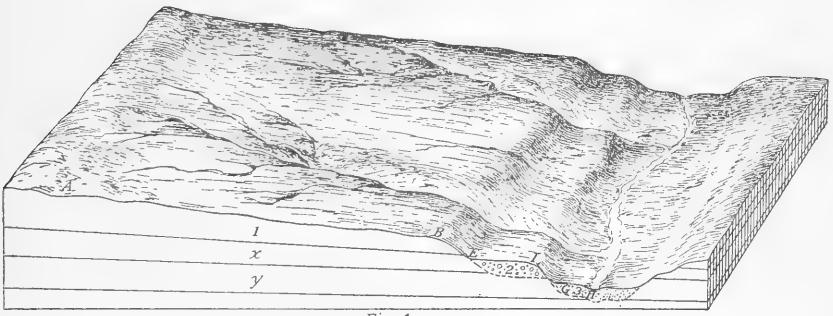


Fig 4

While formation 3 is being deposited, the accumulation of waste on the gentle slopes between formations 3 and 2, and between 2 and 1 is in progress. At this stage then, the detritus on the surface between formations 1 and 2 may be of any age and all ages younger than 1, while that on the slope between formations 2 and 3 may be of any age and of all ages younger than 2.

If subsequently erosion again succeeds deposition, new valleys will be excavated in formation 3 of the main valley, and in the corresponding formation in the tributary valleys.

Complications.—The above illustration embodies the essential principles involved in the development of the *Quaternary* formations of this region, as here interpreted; but the real case is complicated by the fact that the bases on which the several formations, corresponding in a general way to 1, 2 and 3, were deposited, were not plane, and the deposition of the several formations on uneven surfaces complicates their topographic relations. If, for example, the surface beneath formation 1, Fig. 1, were irregular, that formation might, in the depressions of its base, reach a level as low as that attained by the higher parts of formation 2. In this case, there would be no certain way of discriminating between 1 and 2, *on topographic grounds alone,* after erosion has proceeded so far that isolated remnants only of the two formations remain. Corresponding relations might hold between formations 2 and 3. These relations, as a matter of fact, exist.

There is still another complication from the topographic point of view. Thus, while formation 2 was being laid down in the main valley, the corresponding deposits made in a tributary valley rose to higher and higher levels, as the source of the tributary was approached. At the proper distance from the main stream, these deposits in the side valley may have risen to the level of formation 1. Similarly, the deposits made in the valleys of the side streams, while formation 3 was being laid down in the main valley, rise upstream, and, at the proper distance, may reach the level of formation 2 in that valley, or even of formation 1.

Application to New Jersey.—The *Bridgeton* formation is illustrated by No. 1 above, the *Pensauken* formation by No. 2, and the *Cape May* formation by No. 3.

It follows (1) that the borders of the Quaternary formations of this region are not defined by contour lines, though the formations are not independent either of topography or drainage; and (2) that, while there are principal stages of deposition, there are also deposits made at all intermediate stages. If three formations be recognized, corresponding with three principal stages of deposition, it is, nevertheless, impracticable, in some cases, to say with certainty whether a given deposit belongs to one of these

formations or to another, or whether it found lodgment at some time intermediate between the three principal stages of deposition. This is true especially of isolated remnants of one or another of these formations.

The preceding hypothetical cases may be changed to illustrate another phase of the relations of the several members of the series. Let it be supposed that the original plain of deposition covered by formation 1, sloped to the sea. Erosion of its surface by drainage direct to the sea, after its attitude was so changed as to favor erosion, might result in deposition along the shore. The new sediments would be left somewhat as shown by 2, in Fig. 5, the materials of 2 being derived from the higher

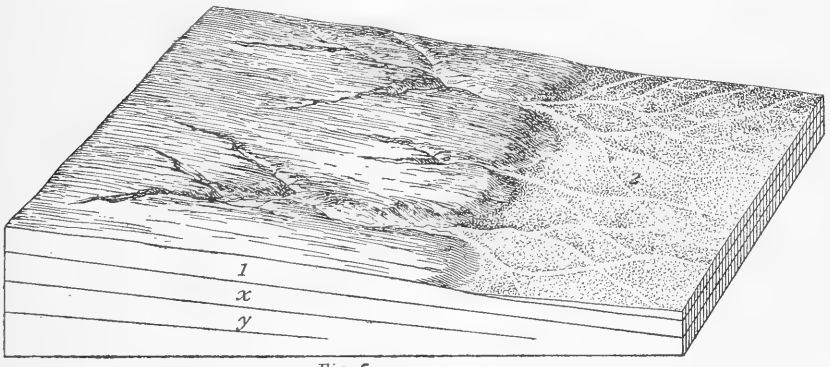


Fig. 5

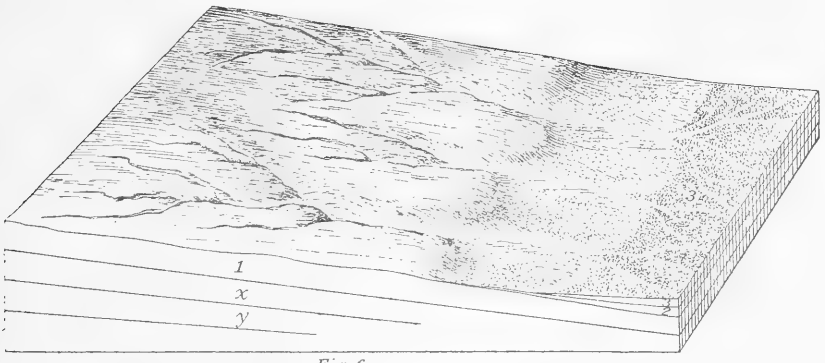


Fig. 6

parts of 1. If this process were repeated, the result would be illustrated by Fig. 6, where a third formation overlies the sea-

ward part of 2. It will be seen that the deposits of successive stages would be even less distinct topographically than in the case where deposition took place in valleys.

If in this illustration it be supposed that there is deposition in the valleys as well as along the shore, the deposits in the valleys would rise upstream, and would not be limited at any fixed height above sea level. The separation of the marine and the non-marine deposits would be difficult, and in places perhaps impossible, *on topographic grounds.*

If we conceive of valley deposition and of shore deposition at the same time, with all the complications involved, we perhaps have the proper conception of the manner in which the Quaternary factors of the Coastal Plain were laid down.

CHAPTER II.

THE BRIDGETON FORMATION.

CONTENTS.

Descriptive Summary.

The Bridgeton is a thin formation, composed chiefly of coarse sand and gravel. But at one place and another it contains sand which is not coarse, loam, and even clay. At the other extreme there are bowlders of considerable size, but they are few and appear to have been chiefly limited, at the outset, to the base of the formation. Owing to the fragmentary condition of the formation, resulting from its extensive erosion, occasional bowlders are the only part which remains in some places, and they appear at the surface not infrequently where streams have cut through the formation, removing all its finer parts.

The formation has two phases which are so unlike that they are best described separately. They will be called the *Glassboro phase* and the *Woodmansie phase*. The former is the better known, and the more distinctive.

GLASSBORO PHASE.

Distribution.—This phase of the formation has its distinctive development in the southwestern part of the State. Its largest continuous surface areas are on the upland which extends southwest from Berlin, and overlooks the lowland bordering the Delaware. Northwest of the escarpment which borders the high land back from the Delaware, there are many outliers of the formation on the crests of hills and divides. Remnants of this phase are found south and west of a line drawn from Berlin down the Mullica River to the Atlantic coast.

Composition.—This phase of the formation consists primarily of gravel and sand, arkose in many places. It contains occasional bowlders, and, exceptionally, seams and lenses of clay. The gravel and sand are dug extensively for road material, and characteristic exposures may be seen in pits at numerous points about Berlin, Atco, Williamstown, Glassboro, Pitman Grove and Cohansey on the upland, and in many of the outliers northwest of the main area, as at Houghton's Hill southwest of

Marlton, at Irish Hill north of Chews Landing, at Adams Hill south of Mickleton, at Point Airy east of Woodtown, and at Big Mannington Hill southwest of the same place. Houghton's Hill and Irish Hill show well the distinctive characteristics.

In more detail, the material of the formation is primarily quartzose. The bowlders and larger cobbles are mostly of quartzite or sandstone, and the smaller cobbles and pebbles are mostly of quartz and chert; but bits and even large masses of crystalline rock, such as granite, gneiss, schist, diabase, etc., are present in most places, though not generally abundant. Some of the pieces of crystalline rock appear to have come from the metamorphic formations along the Delaware below Trenton; but the granitic and diabasic fragments come from other and more northerly sources. Some of them are like rock in the Highlands, from which they probably came, and some are like the igneous rocks of the Newark series. Many of the quartzite and quartzose sandstone bowlders and cobbles are so like the Paleozoic sandstone and quartzite of northern New Jersey as to be indistinguishable from them. Pieces of Highfalls (so-called Medina and Oneida and Shawangunk) sandstone are definitely recognizable; so, also, are bowlders of quartzite derived from the Miocene sandstone which once overspread the Coastal Plain, and which was cemented locally into quartzite, though in most places not cemented at all. The Miocene bowlders are abundant locally, and are known as "bulls heads." Many of them have a pinkish or purplish tone.

Besides the sandstone fragments of quartzitic type, there are large and small fragments of red shale and red sandstone which came from the Newark series to the north, or from some other formation so similar to it as not to be readily distinguished. There are occasional pieces of black shale, similar to the Lockatong shale of the Newark series, and pieces of grayish arkose sandstone which are referred with confidence to the Stockton formation of the same series. The crystalline rock and the red shale and sandstone go together in the sense that where one is found the others are likely to be. They are more common at the base of the formation than in any other part of it, and are most

common in a layer of coarse material a few inches thick at its very bottom (Fig. 9). The crystalline rock fragments, the shale, and other distinctly recognized northern materials decrease in abundance southward.

Much of the sand of this phase of the formation is arkose, and the feldspathic material is, as a rule, completely decayed. The only notable exception is the cores of the larger cobbles and bowlders. The clayey element in the sand is not confined to bits of decayed feldspar; films of clay coat the sand grains in many places, increasing the arkose appearance of the whole.

The quartz of the gravel is mostly vein quartz, and might have come from the Paleozoic and older formations north of the Coastal Plain. Some of the bits of chert contain fossils which have been identified as Devonian. Much of the quartz and chert of the formation appear to have come directly from the Beacon Hill gravel which onece overlay the older formations of the Coastal Plain, but which was largely removed from the northern part of that plain before the Bridgeton epoch. Some of the sandstone and quartzite also came from the Beacon Hill gravel.

Another constituent of the gravel is ironstone; that is, bits of sandstone or conglomerate, with iron-oxide cement. These came from the Coastal Plain formations. Most of them are from the Beacon Hill gravel and the underlying Cohansey sand. Pellets of clay are also found in some places, and these, too, are from the older formations of the Coastal Plain. Locally, the gravel and sand of the Bridgeton beds are cemented by iron oxide.

Structure.—The sand and gravel are, as a rule, cross-bedded (Fig. 7), but in some cases the exposed face in a pit has an almost massive appearance (Fig. 8). In others there is distinct stratification, emphasized to the eye by long lines of pebbles as seen in the vertical face. In other cases, pebbles are scattered through the sand, while in still others, gravel and sand beds alternate.

Thickness.—The remnants of the formation, as now found, vary in thickness from those too thin to be identified definitely,

Fig. 7.

Bridgeton gravel a quarter of a mile east of Cohansey Post Office, Cumberland County, showing characteristic structure.

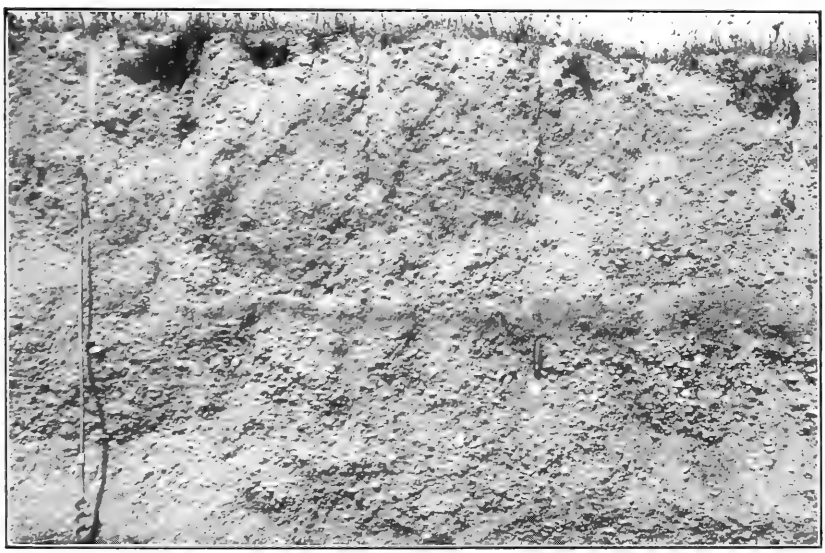


Fig. 8.

Bridgeton gravel east of south of Shiloh, Cumberland County.

up to 60 feet. The maximum thicknesses may represent approximately the original thickness of the formation in the localities where they occur. Sixty feet is probably more than its original average thickness, and less than its maximum.

Since its deposition, much of the Bridgeton formation has been removed by erosion. From large tracts all of it has been taken away, and it occurs in considerable areas only on broad divides.

Original extent.—The Glassboro phase of the Bridgeton formation is believed to have been continuous, at the time of its origin, from Long Island, over much of Staten Island, and across New Jersey along the inland margin of the Coastal Plain; that is, from Long Island to Bordentown and thence down the Delaware Valley to the sea. If this view is correct, it has been removed completely from an area of 5–10 miles wide and 100 miles in length, from Amboy to Salem. The only escape from this conclusion lies in the possibility that the Bridgeton formation has been confused with the Pensauken in the northeastern part of this tract. About Amboy, for instance, the Pensauken reaches high elevations, but its base nowhere seems to reach the altitude which would have been expected of the Bridgeton base.

THE WOODMANSIE PHASE.

Characteristics.—The second phase of the Bridgeton formation is found east and north of the Glassboro phase, southeast of a line extending from Glassboro to Keyport; but within this area the formation is represented at the surface by small areas only, if present identifications are correct. In much of this area, however, the differentiation of the several Quaternary formations is very unsatisfactory. The Woodmansie phase is not arkose, and is without the crystalline rock, shale, red sandstone, etc., of the Glassboro phase. It is more largely of sand than the other phase of the formation, and it is thinner. Its materials were derived chiefly from the Miocene and Cohansey formations. In this region, too, the Bridgeton formation is less distinct topographically than in the Berlin-Bridgeton region,

and its differentiation from other formations is difficult, and, in some places, has not been accomplished.

THE BASE OF THE FORMATION.

Pre-Bridgeton topography.—Both phases of the Bridgeton formation seem to have been deposited on a surface which had some relief, apparently a relief developed by stream erosion. At any rate, the base of the formation is somewhat irregular, and at some points the irregularities are conspicuous within short distances, as if old valleys had been filled by the deposits (Fig. 10). Minor irregularities of other sorts are not rare.

The present valleys do not follow in detail the courses of the valleys which existed before the Bridgeton epoch. Yet the pre-Bridgeton surface developed by stream erosion is thought to have had some similarity to the present surface. Knapp thinks that a master stream had the general course of the Delaware below Trenton, following roughly the line of contact of the older rocks with the Coastal Plain (Cretaceous and later) formations, and that tributaries from the east flowed to this master stream somewhat as now. He believes that these tributary streams headed in a divide which extended roughly from Berlin southwestward to Daretown, a little farther northwest than the present divide between the Delaware and the ocean. Southeast of this divide, the course of the streams is thought to have been southeastward, somewhat as now.

The divide referred to above is thought to have been continued northeastward, with increasing height, through the Clarksburg-Perrineville region, to Crawfords Corner, a few miles south of Matawan and Keyport, and thence to the Navesink Highlands. It was continued thence, perhaps without interruption, across Staten Island to Long Island.

If this divide was uninterrupted throughout this distance, the drainage of the Bridgeton epoch was notably different from that of the present time. It may be noted, however, that the above view held by Knapp, is hardly susceptible of demonstration, and that something may be said for the view that the lower Delaware had a more easterly course than now. This view is favored by

Fig. 9.

Exposure of the Bridgeton formation in the railroad cut at Folsom, Atlantic County, showing a cobble bed in the middle of which there are large slabs of red shale and pieces of crystalline rock. Twenty feet of coarse Bridgeton sand overlies the gravel. The upper part is largely of local origin. Cohansey sand underlies the Bridgeton formation.

Fig. 10.

Bridgeton formation resting upon white glass sand of the Cohansey formation, near Downer, Gloucester County. Note the wavy contact of the two formations.

the distribution of the Glassboro phase of the formation under discussion, as will be seen later.

The remnants of the divide mentioned above are among the most conspicuous features of the topography of the Coastal Plain in New Jersey. The hills at Crawfords Corner (nearly 400 feet high) and Clarksburg are the highest elevations in the southern part of the State. The remnants of the divide farther southwest are lower, but hardly less conspicuous in their surroundings. They are seen in the hills near Ellisdale, in Arneys Mount, and other isolated hills between Clarksburg and Berlin.

If Mr. Knapp's view of the pre-Bridgeton drainage is correct, some idea of the extent to which the former divide has been shifted is made clear by comparing its position, as sketched above, with the present divide between the Delaware and the ocean. The present divide runs from Crawfords Corner, through Freehold, Smithburg, Carr Tavern, Head of Woods, Woodmansie, Tabernacle, and Berlin, to Glassboro.

Northwest of the northeasterly portion of this divide, between Amboy and Bordentown, lay a broad lowland,—perhaps a wide valley plain, in pre-Bridgeton time. This lowland or valley is believed to have been continuous with the valley occupying the site of the lower Delaware. This belt is still a lowland, though it has undergone notable changes since the Bridgeton epoch. The view is entertained that it may have been the course of a large stream, perhaps the ancestor of the Hudson River, which, before the Bridgeton epoch and some of the time since, is thought to have flowed southwestward, reaching what is now the position of the Delaware somewhere between Trenton and Bordentown. If this view is correct, the present outlet of the Hudson, through the "narrows," is of later origin.

In the southwestern part of the State, the Bridgeton remnants have their greatest elevation in the belt of high land extending from Berlin southwestward to Shiloh and Roadstown. West of Bridgeton the base of the formation declines to the southwestward, probably much as the divide of that time did. Southeast of the divide, the base declines to the southeast, toward the ocean. Northwest of the divide, the base declines somewhat

toward the supposed pre-Bridgeton Amboy-Bordentown-Salem valley. This decline points to a tract along the present Delaware Valley at least 40–50 feet below the low divide to the southeast, at the time the Bridgeton formation was deposited.

Similar relations hold northeast of Berlin. The erosion surface on which the Bridgeton was deposited, or the plain which appears to be the continuation of it, has now an elevation of about 200 feet at Berlin, and thence to Freehold. Above it rose the unreduced hills of the Clarksburg and Crawfords Corner regions. This old plain appears to have sloped southeastward from the divide, declining to 140 feet at Lakewood, 130 feet at Barnegat, 60 feet at Absecon, and 40 feet at Tuckahoe. North of the Amboy-Bordentown Valley, areas at about 200 feet, as in the vicinity of Pennington, may go with this old level. There are tracts of similar elevation in Pennsylvania, as at Norristown, Conshohocken, King of Prussia, Gordon Heights, and along the line of the Pennsylvania Railroad known as the "Cut Off," running southwest from Trenton.

ORIGIN.

According to the interpretation here favored, the accessible parts of both phases of the Bridgeton formation are primarily of terrestrial origin. A part of what now remains may be marine or estuarine, and part of what has been removed may have been.

The Glassboro Phase.—The material of the *Glassboro phase* of the formation is believed to have been brought in largely from the north by rivers, and deposited in the wide valley between Amboy and Salem. The antecedent of Hudson River was one of the chief contributors, if it had the course suggested above. Another principal stream from the north was the ancestor of the Raritan, which, at that time, is believed to have flowed up the present Millstone valley to the Amboy-Trenton valley. In the western part of the State, some of the gravel and sand of the formation were probably brought in by the Delaware, and at Philadelphia, the Schuykill made it contribution. Streams lead-

ing to the Amboy-Trenton valley from the Coastal Plain brought in sand and gravel from the Cretaceous and Tertiary formations over which they flowed.

West and southwest of Berlin, the Trenton-Salem valley (assuming the drainage to have followed this course) is thought to have been filled up to the level of the divide on its southeastern side, while northeast of Berlin, where the divide was higher, the valley is thought not to have been filled completely. Where the divide was buried, as south of Berlin, material of the sort which filled the valley was spread out to the southeast over the the seaward slope.

The deposits made by the southward-flowing drainage came from areas of crystalline rock, and were somewhat arkose, and the arkose (Glassboro) phase of the formation probably finds its explanation in the drainage of the time. It is limited to the area reached by streams from the crystalline rock to the north. The material of the Woodmansie phase, deposited by streams heading in the Coastal Plain, is not arkose, and is without the distinctive northern constituents which characterize the Glassboro phase.

The composition of the Glassboro phase of the formation seems to be best accounted for on the supposition that the drainage which was responsible for it was glacial drainage, and therefore that the formation was contemporaneous with a glacial epoch. If this is the case, the glacial epoch was the earliest of which there is record in this region. On this hypothesis, the materials of the formation came partly from the basin of the Hudson River by way of Amboy and Old Bridge, and partly from the basins of the upper Raritan and Delaware rivers, both of which joined the main stream through the Amboy-Salem valley. All of these streams are thought to have flowed from the ice, and to have carried such debris as glacial streams carry.

The points which have led to the tentative adoption of this view, may be stated briefly. (1) Much of the material of the formation has the composition which glacial outwash would have had. The association of Triassic, granitic, and Paleozoic

materials, some of them non-resistant, but all from the same direction, and all from terranes known to have been crossed by the ice of an early glacial epoch, favors the view here suggested. On the other hand, the abundance of material derived from the Coastal Plain formations south of the ice is to be explained by the following facts: (a) The existing deposits are some distance from the ice, the irregular edge of which probably extended from Manhattan on the east, to Riegelsville on the Delaware; (b) the easily erodable nature of the Coastal Plain formations, drainage from which flowed to the main depositing stream; and (c) the climate conditions, favorable to erosion in the Coastal Plain at the time the Bridgeton gravels and sands were deposited. (2) Occasional bowlders in the Bridgeton formation are as much as 5 feet in diameter. Floating ice seems to be called for in their transportation. Especially do slab-like masses of red shale and sandstone, 40 to 60 miles from their nearest possible source, seem to demand floating ice for their carriage, for, apart from their size, it does not appear that any other agent of transportation could have got the weak masses of shale to their destination without comminution. (3) The likeness of the stony material of the early glacial drift to the coarse material of the Bridgeton formation is great. This likeness applies to the physical condition of the bowlders, as well as to the kinds of rock involved. (4) The arkose character of much of the sand is suggestive of a glacial origin. It is difficult to see how such quantities of such material could have been formed and carried so far from its sources, under normal conditions of river action, or by any combination of rain and river erosion with waves and shore currents. (5) The structure of the Bridgeton is very similar to that of glacial outwash, though it is recognized that this structure is not especially distinctive.

This general view does not in itself preclude the hypothesis that the land may have stood somewhat lower than now in the Bridgeton epoch or during some part of it,—low enough, perhaps, to have permitted marine deposits within the area of the present land. But paleontologic evidence of marine deposits of this epoch within the area of the State is wanting.

If the above view concerning the origin of the Bridgeton is correct, corroborative evidence might be expected on the Pennsylvania side of the Delaware, and along the northwest side of the Amboy-Bordentown lowland. The evidence afforded by these regions is meager, though consistent with the view stated above, so far as known. Gravel and sand which may be interpreted as remnants of the Bridgeton formation are found on the west side of the Delaware at various points between Trenton and Chester; but they are so meager as to leave any conclusion drawn from them open to question. If they are remnants of the Bridgeton formation, their meagerness may find a sufficient explanation in the fact that the Delaware flows near the western edge of the supposed pre-Bridgeton valley, and that the Bridgeton formation has therefore been more completely removed from this side of the valley. When the narrowness of the tract on the west side of the stream low enough to have received Bridgeton deposits is considered, it is unlikely that considerable remnants of the formation would have escaped erosion. The case is much the same northwest of the Bordentown-Amboy valley in New Jersey; but evidence that the Bridgeton or some formation similar to it once covered this region, is conclusive.

Northeast of Berlin, Bridgeton remnants in the old Amboy-Bordentown valley are absent, or, if present, have not been identified. It is probable that no deposits of this time, made by drainage through the main valley, persist.

This conception of the origin of the Bridgeton formation is not without difficulties. It is not clear, for example, how streams, even with the help of floating ice, could have carried bowlders and large slabs of weak rock from the Newark series, to Hammonton, New Germany (Folsom), and Buck Hill. If streams were the agents of transportation, the course of drainage must have been very different from that of the present time, and there is some evidence that it was not. If, on the other hand, the bowlders and slabs of weak material were floated to their destination in sea water, a submergence of more than 100 feet would be called for, and of this there is no clear evidence. If the master stream of southern New Jersey flowed further east than the

lower Delaware, it would help to explain the southeastward extension of the arkose phase of the formation, and the occurrence of arkose material and its accompaniments, at the localities just mentioned.

The former drainage.—The considerations seeming to point to the course of the ancestor of the Hudson River across New Jersey along the Amboy-Bordentown valley, are as follows: (1) The great volume of the Bridgeton sediments, calling for a large amount of running water, if the deposits are fluviatile; (2) the character of the sediments, pointing distinctly to a northerly source, a character which is quite as evident at the northeast (as about Amboy) as at any point in the valley farther southwest; (3) the tendency of rivers to choose courses along the contact of the Coastal Plain formations with the older and harder formations makes this the appropriate site of a great valley; (4) the topography and drainage south of the Amboy-Bordentown valley, in the eastern part of the State, suggest that drainage flowed northwestward until recent times. Between Matawan and Freehold, for example, Deep Run and Matchaponix Brook, leading to the northwest, are the dominant streams, and their courses suggest a former connection with a southwesterly flowing stream. Matawan and Cheesequake creeks, flowing eastward, are of minor importance, and apparently younger.

The gap in the Rocky Hill range at Kingston probably was utilized by the Raritan when it flowed up the present Millstone valley to join the main stream flowing southwest toward Bordentown. The gorge was probably started after the Beacon Hill epoch. The configuration of the gap itself suggests two stages of history. Its upper part (above the level of 160 feet) is broader, and that below is narrower. The upper part is probably pre-Bridgeton, the lower post-Bridgeton. The part above the 160-foot level perhaps goes with the general plain of erosion which now has an altitude of about 200 feet in the region from Freehold to Berlin, and at Pennington, and is somewhat lower farther south. The river which flowed through the upper part of the valley of Stony Brook, probably joined the same stream that the Raritan joined.

The great river which flowed from the northeast to Trenton or Bordentown probably held this course long after the deposition of the Bridgeton gravels—long enough, indeed, to remove that formation from a belt 5 to 10 miles wide. Knapp thinks there is some evidence that before the deposition of the Pensauken formation, small streams comparable to the upper Millstone River, Manalapan Creek, and Assanpink Creek, heading in the Clarksburg region, flowed northwest across the lowland, some of them turning finally to the northeast, and some to the southwest. Before the Hudson was diverted, it had developed a lowland 30 to 50 feet below the prevailing pre-Bridgeton level.

If the above conclusions are correct, the Hudson was diverted before the deposition of the Pensauken gravels. The method of diversion is not known. If it was not by piracy, it may have been by wave cutting, which conceivably opened up connection between the sea and that part of the stream above Staten Island. Knapp thinks that the first diversion of the Hudson from its old valley was not to its present course, but that it was either eastward, north of Long Island, or, following the suggestion of Veatch, across the western end of Long Island in the vicinity of Jamaica.

Whatever the time of the diversion of the Hudson, and whatever its course in pre-Pensauken time, it seems to have reëstablished its course to the southwest during the Pensauken epoch. This might have been the result of the blocking of the eastern outlet by glacial drift, or by outwash from the ice in the glacial epoch contemporaneous with the deposition of the Pensauken formation.

The above hypothesis as to the former course of the Hudson is not without difficulties. Thus the surface of aggradation should have been at least 50 feet higher, say at Freehold, than at Berlin, to make transportation to the southwestward possible. If it had been built up 50 feet higher at Freehold than at Berlin, the gravel would have been carried over the divide to the southeast, unless the divide was then higher (which is not improbable) than now; but gravel of this sort is not found southeast of the divide. Again if the Freehold divide was then high enough to

stop the overspread of gravel and sand to the southeast, the valleys down the southeast slope should have shown the effect of this altitude; but such effects have not been recognized. It would seem, therefore, either that the region about Berlin must have been lower then than now, relatively, or elevated since. While fluvio-glacial waters were depositing sand and gravel along the lines of their flow, other sands and gravels must have been accumulating in the valleys which did not carry glacial waters. In valleys tributary to the Delaware there must have been deposits of sediment brought down from higher parts of the Coastal Plain, while the Delaware Valley itself was being filled up with fluvio-glacial debris. If the southern part of the State was then lower than now, floating ice may have had a share in the remarkable deposits referred to the Bridgeton formation, such as those about Folsom, Hammonton, Tuckahoe, etc., where the large blocks of soft red shale and sandstone appear to be so anomalous as to make the presence of floating ice seem necessary. Possibly the southern part of the State was low enough during some stage of the epoch, to convert the area of the present lowland between Raritan Bay and Trenton into a sound; but of such submergence specific evidence is wanting.

The Woodmansie Phase.—While the deposition of the Glassboro phase of the formation was in progress, other deposits were being made by the streams which were not so situated as to receive glacial drainage.

Theoretically, the deposits made in the valleys of streams flowing to the southeast from the divide northeast of Berlin, at the time sedimentation by fluvio-glacial waters was in progress in the main Delaware Valley, constitute the second (the Woodmansie) phase of the Bridgeton formation, which is confined to the area southeast of the Amboy-Bordentown Valley, and north of Mullica River. Practically, the deposits of this time in this area are difficult of indentification. They possess none of the distinctive features of constitution which are relied on for identification of the Bridgeton formation farther south and west, and their topographic positions become less and less distinctive as sea level and the coast line are approached. Neverthe-

less we may recognize certain beds, which, from their topographic relations, we infer to be of Bridgeton age. These gravels, sands, etc., were derived from local formations, and must have been deposited under conditions which were somewhat different from those of the present time. These conditions may have been either climatic or topographic, or both. If, for instance, the Bridgeton epoch was an epoch when the land was sinking, so that the ocean encroached upon it, marine deposition must have taken place in the lower ends of the valleys and along the coast.

Local Details.

THE GLASSBORO PHASE.

GENERAL OCCURRENCE.

The largest areas of the Bridgeton formation occur in the northeast-southwest belt between Berlin and Shiloh (a few miles west of Bridgeton), along the divide between the drainage which flows westward into the Delaware and that which flows to the southern and southeastern coast. But even here the continuity of the formation is interrupted by the headwater tributaries of Great Egg Harbor and Maurice rivers, and of Timber and Mantua creeks. A line drawn from Clementon southwest through Mullica Hill, Harrisonville, Yorktown and Roadstown (5 miles west of Bridgeton) would mark approximately the northwestern limit of all considerable areas of the formation, though to the northwest of this line small outliers cap some of the higher hills which have been separated from the highland to the southeast by erosion.

The general relations of the Bridgeton formation will be brought out in connection with a series of sections, mostly at right angles to the strike of the formations of the Coastal Plain. The order in which these sections will be described, is from the south to the north.

SOUTH OF ALLOWAYS CREEK.

Distribution.—The first of the sections extends from the Delaware opposite Salem, through Burden Hill and Shiloh to Cohansey Creek and beyond. This section (Fig. 11)[1] shows the Bridgeton formation capping all the level lands along this line above the elevation of 110–120 feet. At a lower level to the west, mostly below 60 feet along the line of the section, is a second formation, the Pensauken, from which the Bridgeton is here thoroughly distinct topographically, though the two are much alike in composition. This section is fairly typical of the southwestern part of the State.

The most westerly remnant of the Bridgeton formation is about 6 miles east-southeast of Salem, and about 2 miles southeast of Quinton, at Burden Hill. The summit of the hill has an elevation of about 130 feet, and the base of the formation is 20 or 30 feet lower. The gravel and sand, principally the latter, are arkose.

East of Burden Hill the formation covers the higher hills and uplands forming the broad divide between Cohansey Creek on the east and Stow Creek and Alloways Creek on the west. The general relations of the formation, topographically and stratigraphically, are shown in Fig. 11, which makes it clear that the formation antedated the development of the lowland along the Delaware.

Unevenness of base.—From Burden Hill southeast to Bridgeton, the base of the formation declines from about 110 or 120 feet, to about 80 feet, or about 30 feet in 10 miles; but since the base of the Bridgeton is uneven, it can hardly be assumed that this is its average dip to the southeast. The formation, indeed, does not have so regular a dip as the older formations on which it rests. Its base declines slightly toward Cohansey Creek from both sides, suggesting that there was a valley in pre-Bridgeton time near the site of this stream. This and many other harmonious facts indicate that the formation rests on an erosion surface of slight relief.

[1]Figs. 11, 15, 16, 18, 19, 20, 22, 23, 24, 25, 26, 27 are on Plate A, facing p. 40.

The unevenness of its base may be seen at various points, as at the headwaters of Deep Run, east of Dilks Mill. Three-fourths of a mile east of this mill, and a mile southwest of Friesburg, the base of the Bridgeton has an altitude of about 120 feet. South of this point, the base runs down to 90 feet within a mile. The low level is interpreted as representing a pre-Bridgeton valley, but here, as in some other cases, it is possible that the low level of the Bridgeton material is the result of downslope creep since the adjacent valleys were excavated.

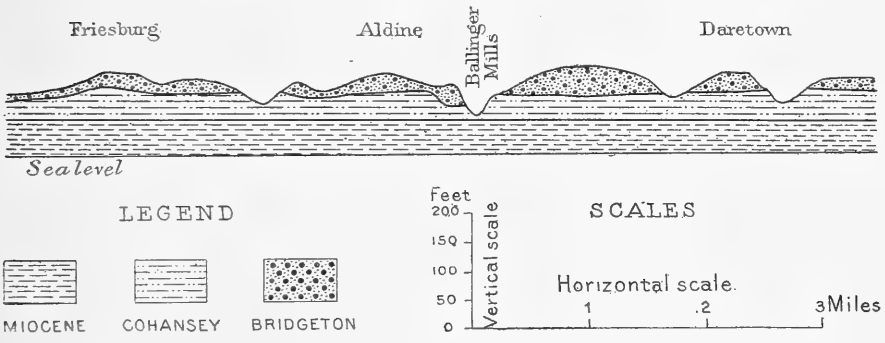


Fig. 12.

Relations of the Bridgeton along a section from Friesburg to Daretown.

About Aldine, the base of the Bridgeton formation is notably irregular. At Aldine it has an altitude of about 110 feet, but half a mile to the west, 120 feet. Half a mile north, there is a headland at Ballinger's Mill, which has an elevation of 120 feet. The mill pond has an elevation of 84 feet, and the base of the Bridgeton is but a few feet above it. The general relations of the formation are shown in Fig. 12. To the west, east, and south of Aldine, the base of the formation is not below 100 feet, and is in many places 100 to 120 feet, so that the old valley where the base of the Bridgeton appears at 90 or below, seems to have had its outlet to the west.

Constitution.—To the west, the constitution of the formation is normal, but in the region about Bridgeton it is difficult, in many places, to distinguish the Bridgeton formation from the Cohansey which underlies it. Locally most of the material of

the younger formation was derived from the older, and there the distinction is most difficult, for the Bridgeton is not arkose. At Harris's Quarry, 1¾ miles southwest of Cohansey, and 1½ miles southeast of Pecks Corners, at the 100 to 110-foot level Fig. 13, p. 30), the sand is cemented into ferruginous sandstone, which, for the most part, resembles the Cohansey formation rather than the Bridgeton; but the occasional cobbles and large pebbles seem to indicate its correlation with the Bridgeton, for coarse gravel is absent, so far as known, from the Cohansey sand. Material which is similar, except for the gravel, is to be found in the south bank of Hepnor Run, 2 miles south of Bridgeton. In this latter place, there is nothing to favor the reference of the sandstone to the Bridgeton formation, as against the Cohansey.

Where the Cohansey sand is coarse, and especially where it is associated with fine gravel, as is the case in many places, and where the Bridgeton is of coarse sand with only fine gravel intermixed, the two may be inseparable on the basis of available data.

The Bridgeton formation of the Bridgeton region may be said to center about Elmer, beyond the headwaters of Alloways Creek and Salem Creek. Considerable areas extend off to the south on the divides east and west of Cohansey Creek. Within this general area the altitude of its surface ranges from about 160 feet to 100 feet, and its base has a smaller range from 120 feet at the north to 80 feet at the south.

BETWEEN ALLOWAYS CREEK AND OLDMANS CREEK.

Distribution.—The Bridgeton formation caps the divide between these creeks, extending out to the northwest from the highlands to the southeast. Northwest of the main divide between these creeks, there are outliers of the formation on hills which have been isolated by erosion. The general relations of the formation are shown in Figs. 14 and 15 (p. 40).

On the uplands to the east the surface of the Bridgeton has an altitude of 140 to 160 feet. The tops of the outliers to the west have an altitude ranging as low as 129 feet on Big Mannington Hill. The original surface of the formation at the east

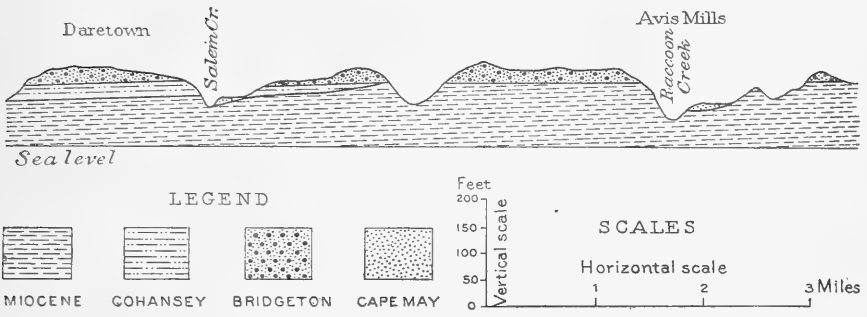


Fig. 14.

Section from Daretown to Avis Mills, Oldham Creek.

appears to have corresponded with the present altitude of about 150 to 160 feet, and the lower altitudes of the surface now, are due to subsequent lowering by erosion.

The base of the formation here has an elevation of 100 to 120 feet. Its thickness therefore reaches 40 to 50 feet, and perhaps occasionally even 60 feet. This conclusion is drawn from the elevation of the surface, and the known altitude of the base at various points. No thickness of 60 feet has been seen in section, but thicknesses of 45 feet are indicated at several points by the records of wells.

About Daretown, the base on which the Bridgeton rests is not very irregular, as shown by Figs. 14 and 15. Such irregularities as that shown in Big Mannington Hill may be partly or wholly the result of displacement of the surface material. If not, this outlier indicates that the pre-Bridgeton surface declined a little to the west.

The relations of the Bridgeton formation north of Salem Creek are much like those to the south. Thus about Whig Lane, the broad interstream areas are generally covered with Bridgeton gravel and sand. To the west, the formation becomes more and more dissected, and its last remnants in this direction are small outliers such as that seen on the hill 1½ miles southeast of Auburn (Fig. 16, p. 40). The base of the formation is rather even along this divide, so far as known, and slightly higher than south of Salem Creek, ranging from 120 to 130 feet. At points,

however, as about Avis Mills, the base is a little lower. The maximum thickness of the formation here is 40 feet, or possibly a little more.

Exposures.—There are good exposures of the Bridgeton formation between Salem Creek and Oldmans Creek. One is at a gravel pit three-fourths of a mile north of west of Pitts Grove (Pole Tavern), where 7 or 8 feet of gravel carrying cobbles and occasional bowlders may be seen. The formation here rests on the glass-sand phase of the Cohansey formation. The gravel is compact, and is distinctly stratified in rather regular horizontal beds. Bits of crystalline rock are common, though no red shale was seen. A mile northwest of Whig Lane is another good exposure showing 6 or 7 feet of compact gravel with only sand enough to fill the interstices between the pebbles. Another pit 1½ miles northwest of Whig Lane, on the cross road to Avis Mills, shows gravel finer than that at the pits mentioned above. The gravel here has a strong resemblance to that of the Beacon Hill formation. A mile east of Point Airy is another pit (Fig. 17) showing 7 feet of gravel with occasional bowlders of brown standstone or quartzite. The constituents characteristic of the Bridgeton, that is the crystalline rock and the red shale, are present.

BETWEEN OLDMANS CREEK AND RACCOON CREEK.

Distribution.—The general relations of the Bridgeton in this area are shown in Fig. 18. The large area of Bridgeton to the southeast (about Hardingville in the section) is continued westward between the creeks to Fairview and Lincoln. West of that place, the continuity of the formation is interrupted by valleys. Considerable outliers occur north of Harrisonville, and smaller ones south and southwest of Swedesboro, the one farthest west being on Scull Hill.

The altitude of the Bridgeton surface about Fairview is 140 to 150 feet, and the top of Scull Hill is 146 feet. The remnants between these places are on hills of similar altitudes. Here therefore the base of the formation does not decline toward the Delaware.

Fig. 13.

Gravel and coarse sand cemented to stone and quarried for building purposes near Cohansey Post Office. Either the Cohansey or the Bridgeton formation.

Fig. 17.

Bridgeton gravel 1 mile southwest of Harrisonville, Gloucester County. Shows characteristic alternation of beds of almost solid gravel with layers of coarse compact sand carrying a few pebbles.

In most places, the Bridgeton of this immediate region rests on the Miocene, but on Scull Hill it appears to lie on the Cretaceous. The base of the Bridgeton shows itself topographically on the slopes of many of the hills, especially where underlain by Miocene, in an increased angle of slope. This is because the Miocene beneath is somewhat less resistant than the Bridgeton.

A feature of the Bridgeton of this region is the presence in it of an occasional bowlder of Miocene quartzite (locally known as "bull's head" bowlders). These peculiar bowlders are rather common south and southwest of Swedesboro, within a radius of 3 or 4 miles. At few other points are they so abundant. They are, however, wide-spread, and seem to point to extensive weathering and erosion of the Miocene after some parts of it had become indurated. Bowlders of this sort exist as far east and south as Hammonton, Folsom, and Tuckahoe.

Exposures.—A mile northwest of Harrisonville, in the 134-foot hill, a gravel pit shows 12 feet of compact sand and gravel, more or less cemented. There are other exposures between this point and Mullica Hill to the northeast, and Swedesboro on the northwest.

BETWEEN RACCOON CREEK AND MANTUA CREEK.

Distribution.—Between the upper courses of these creeks in the vicinity of Richwood (Five Points), the Bridgeton forms a nearly continuous mantle over older formations. About Glassboro and to the northwest the continuity is interrupted, as in corresponding situations farther south, being restricted at the east to the divides, farther west to the higher parts of the divides, as about Jefferson, and finally to the tops of isolated hills. The most northwesterly remnant is at Adams Hill, a mile or so east of Mickleton. The general relations of the formation between these creeks is shown in Fig. 19. This section corresponds, in all essential respects, with Figs. 16 and 18, farther south.

The relation of the Bridgeton to the Pensauken is well shown about Mickleton. The arkose phase of the Pensauken lies below 100 feet, and above this level Adams Hill rises to 133 feet, capped by an isolated remnant of the Bridgeton, which is litho-

logically very like the Pensauken, but topographically very distinct from it. Adams Hill corresponds topographically and in its capping of Bridgeton, to Big Mannington and Scull hills, already referred to. To the southeast, at Richwood, the surface rises to 176 feet. The thickness of the Bridgeton here appears to be nearly or quite 60 feet.

At Jefferson the surface of the Bridgeton has a maximum elevation of 166 feet, and its base an altitude of 120 to 130 feet; but this probably does not represent the full thickness of the formation as originally deposited. A mile and a half north of Pitman Grove, remnants of the Bridgeton appear at various levels between 120 and 150 feet, while the base ranges from 110 to 130 feet, and possibly even below the lower of these elevations at some points.

An uncertain patch.—A half mile west of Hurffville, west of Mantua Creek, is a hill having a summit altitude of 93 feet. There are gravel pits on the east side of this hill, showing a maximum depth of more than 20 feet of gravel, more or less cemented into conglomerate. The gravel contains shaly material.

This patch of gravel is one of the most puzzling in the entire area. It is much lower than the proper horizon of the Bridgeton, and is at the proper level for the Pensauken. On the other hand, the constitution of the material seems to put it with the Bridgeton, for the Pensauken of this region is not arkose, and does not contain red shale, unless this remnant is Pensauken. If it is Bridgeton, its base is considerably lower than that of any other remnant of this formation in this vicinity. If it is Pensauken, it is unlike any other Pensauken material in this immediate vicinity in constitution. It may be a deposit derived from the original Bridgeton, still retaining some of the soft materials characteristic of that formation, though not now in its original position, or it may be a mass of Bridgeton material displaced from its original position, at a time when the topography was very different from what it now is.

The base.—The base of the formation in the vicinity of Richwood is somewhat irregular, the observed range in altitude being from about 105 to 140 feet. The formation, which is

here gravelly, rests on characteristic fine Miocene sand, and the distinction between the two is therefore clear. In general, the base declines toward Edwards Run on the west, and towards Chestnut Branch on the east.

The base is much more regular about Cross Keys, Downer (about 150 feet), and Glassboro (about 140 feet) than about Barnsboro and Jefferson. In the vicinity of Barnsboro, indeed, it is evident from the base of the formation that there were pre-Bridgeton valleys leading westward toward the Delaware. The irregularities of base here are similar to those about Aldine (p. 27). There are also some irregularities in the base of the Bridgeton in the vicinity of Pitman Grove and Dilkesborough.

Exposures.—A mile or more northwest of Barnsboro, there are gravel pits, showing the nature of the Bridgeton at this locality. Some of the material is coarse, ranging up to bowlder-size, and the gravel is compact. In some exposures, the gravel is confined mainly to the base, and in some places there is a conspicuous cobble bed in this position.

There is another exposure a third of a mile or so southeast of Barnsboro, on the Pitman Grove road, where 15 feet of Bridgeton gravel overlies the Miocene. There is rather less sand, loam, etc., associated with the gravel here than in most places, and the gravel itself is finer than is its wont. At Pitman Grove there are extensive exposures along the railway showing the base of the formation at an altitude of about 120 feet. Its base has the abundance of foreign material characteristic of the gravelly layer at the bottom. Bowlders even 3 feet or more in diameter are to be found, though they are rare.

BETWEEN MANTUA CREEK AND BIG TIMBER CREEK.

Distribution.—Between the headwaters of these creeks, and between the upper parts of the south and north branches of Timber Creek, south of Point Pleasant, the Bridgeton formation is found in considerable areas at elevations of 150 to 170 feet; but northwest of Cross Keys it is found only on the divides (Fig. 20). Its most northwesterly remnant is on Irish Hill,

north of the north branch of Timber Creek. Its general relations are shown in Fig. 22, which is slightly diagrammatic and slightly composite, since it brings in hills which lie a little to one side or the other of a straight line.

North of Davidstown, there are two areas within a mile of each other, covered with remnants of the Bridgeton formation. In both cases, it is thin and more or less cemented, and in both it probably represents no more than the base of the formation which has escaped erosion.

Exposures.—Exposures are plentiful. A mile southeast of Green Tree, at the school house, 4 to 6 feet of gravel are exposed, similar to that of the Beacon Hill formation; but since it contains bits of red shale, it is regarded as Bridgeton. There is another exposure a mile northeast of Green Tree in the 166-foot hill, and several about Creesville. In the 125-foot hill three-fourths of a mile east of Hurffville, 7 feet of gravel characteristic of the formation are exposed between the levels of 110 and 120 feet. The gravel is very compact and more or less cemented, with a characteristic bed of coarse material, containing shale, at the base. Another characteristic exposure was seen in the 153-foot hill 1¼ miles northeast of Hurffville, where the partially cemented gravel contains pieces of red shale up to 4 inches in diameter; and another in the 134-foot hill, east of Mechanicsville. Other exposures occur in lower hills, where the correlation of the material is open to question.

Between Davidstown and Spring Mills, there are two hills which rise to the Bridgeton level (about 140 feet). In the more southwesterly of these hills, about a mile from Davidstown, there is a good exposure of the Bridgeton formation which contains more than the normal amount of coarse material, the bowlders ranging up to 2 feet in diameter. They include a variety of sandstones, quartzose schists, conglomerate, and quartz. The base of the formation here has an elevation of about 130 feet. The character of the material is illustrated by Figs. 10 and 21 (pp. 16 and 42).

Base.—The base of the formation has an elevation of about 150 feet at Cross Keys, but declines to 135 feet at Green Tree. Still farther northwest, between Creesville and Hurffville, outliers

of gravel occur at lower levels, ranging down even to 105 feet. Some of them appear to be Bridgeton in situ, while others may represent displaced remnants of the formation let down a little from their original position. The most northwesterly remnant is 1½ miles south by southeast of Woodbury, capping a 144-foot hill (Reservoir Hill). There is a considerable plain at about 100 feet surrounding this hill, and on the plain there is much gravel younger than the Bridgeton. The distinction of the two formations, topographically, is brought out in Fig. 20. Reservoir Hill corresponds with Adams Hill (Fig. 19) and Big Mannington Hill farther southwest. The base of the Bridgeton is lower about Creesville than elsewhere in the vicinity.

At Point Pleasant (Camden County), the formation is found up to levels of 191 feet, its base being about 15 feet lower. At Davidstown, Mechanicsville, and Irish Hill, it is at levels of about 140 feet, the altitude of its base ranging from 120 to 135 feet.

The distinctness of the Bridgeton and Pensauken is well shown about Irish Hill (Fig. 22). About Bell Mawr, the arkose phase of the Pensauken is restricted mainly to the 80-foot level. About Irish Hill, at the 100± level, there is Pensauken of the phase which occurs at a distance from the Delaware. Irish Hill, which has a Bridgeton cap, rises distinctly above these surroundings. The Bridgeton here is essentially the same in constitution as that about Point Pleasant, at elevations of 180–190 feet. It has all the characteristic Bridgeton marks, namely, arkose sand, shale, and bits of crystalline rock.

AREAS ABOUT BERLIN AND FARTHER NORTH.

Haddonfield.—About Berlin the Bridgeton caps the higher hills, but to the west there is an area of about four square miles where it forms a continuous cover. This area extends from Albion on the south, to a point a mile east of Gibbsborough on the north. The surface altitude ranges from 170 to 200 feet, and the base lies at elevations ranging from 150 to 200 feet. West of this area is the escarpment overlooking the broad low-

land along the Delaware. Six miles to the northwest of this escarpment, near Haddonfield, is an isolated hill (Fig. 23), the top of which has an elevation of 140 feet. This hill has a thin cap of gravel which is correlated with Bridgeton on topographic grounds, good exposures of the material not being seen. This is the only remnant of the formation between Gibbsborough and the Delaware.

The upper limit of the Pensauken formation about Haddonfield is about 120 feet. The isolated hill at 140, with its cap of gravel, is somewhat conspicuous. The gravel of this hill is not distinguishable, lithologically, from the Pensauken, but topographically the hill clearly belongs with Irish Hill 3 miles to the southwest, and with Adams and Big Mannington hills still farther southwest.

Houghton's Hill.[1]—Two miles southwest of Marlton and 4 miles southeast of Haddonfield, is Houghton's Hill, which has a summit elevation of 181 feet. The gravel pit at its top shows 30 feet of Bridgeton gravel and sand (Fig. 24). The assortment of the material here is less perfect than in most sections of the Bridgeton formation. The larger part of the coarse material is at the base, where shale in pieces up to 2 inches in diameter is conspicuous. In the main part of the section, there is little loamy material, and the sand is less compact than is the habit of the formation. It consists of coarse sand and fine gravel, and makes fairly good road material, more because of the abundance of soft cherts, than for any other reason. The relations of this remnant are indicated in Fig. 24 (p. 40).

Albion.—North of Berlin the 214-foot hill has no Bridgeton at its summit. The hills of this elevation appear to have risen above the level of Bridgeton deposition, but they may not now have the altitude which they had during the Bridgeton epoch. About Albion, Bridgeton occurs at lower levels, perhaps as low as 150 feet; but south of Clementon the 202-foot hill seems to be free from Bridgeton material. The trace of gravel over it may have been derived from the Beacon Hill formation so far as present evidence shows.

[1]On recent map of the Survey this is "Hutton's Hill."

Between Berlin and Atco.—The Bridgeton is present over a considerable area between Berlin and Atco, and is well exposed a mile northwest of the latter place. The material here is very like that at Pitman Grove, except that the sand is less arkose. Most of it appears to have been derived from the Cohansey formation.

ON THE DIVIDES BETWEEN BERLIN AND GLASSBORO.

The main divide between the Delaware and the ocean, in pre-Bridgeton time, appears to have extended from Daretown, via Whig Lane, Cross Keys and Mount Pleasant, to Berlin. Northwest of this main divide, the slope was steep and irregular; to the southeast it was gentler and less irregular. South of Berlin, the Bridgeton formation seems to have overspread this divide, where it was lower than to the north. Its failure to overspread it from Berlin to Freehold and beyond was probably because the divide was too high.

Lower land northwest of the main divide at the time of Bridgeton deposition is indicated by the decline in the base of the Bridgeton formation northwest of the escarpment, and by the numerous irregularities in its base in the vicinity of Green Tree, Pitman Grove, Barnsboro, Jefferson, and Aldine. These irregularities point to northwesterly drainage in pre-Bridgeton time. The lower land northwest of the divide appears to have been some 40 to 50 feet below the main divide.

IN THE AREA OF SOUTHEASTERLY DRAINAGE.

Southeast of the divide which limited streams flowing to the Delaware, the drainage appears to have gone directly to the ocean. The relations of the Bridgeton from Berlin to Glassboro are shown in Fig. 25, which is somewhat diagrammatic. It represents the Bridgeton as pinching out to the northeast, with the rise of the base on which it rests. The upper limit of the Bridgeton material about Berlin seems to have been about 200 feet. To the south and southwest, where the divide was lower, the

Bridgeton was thicker (50 to 70 feet about Richwood, Whig Lane, and Daretown).

The character of the Bridgeton is well shown in numerous exposures between Berlin and Glassboro. There is a large pit at West Berlin (altitude 180 feet) which shows 7 or 8 feet of coarse arkose sand with a little gravel, very compact, and available for road material. At the base of the section, crystalline material and shale appear in a layer 6 inches to a foot in thickness. Lumps of clay rounded into the form of pebbles appear in the same layer. A mile north of West Berlin there is another pit, at an elevation of 180 feet, which shows 10 feet of material like that at West Berlin. The exposure in Houghton's Hill has been referred to already.

WEST OF COHANSEY CREEK.

The Bridgeton formation is well developed on the divide west of Cohansey Creek, from Aldine to the scarp a mile or so south of Roadstown. It also covers the divides between the tributaries to Cohansey Creek, extending nearly to the main stream southeast of Cohansey, east of Shiloh, and northwest of Bridgeton. It extends westward on the divide between the headwaters of the tributaries of Stow Creek. Its base has an elevation of about 100 feet at the north, and 90 feet at the south, and its presence s nearly universal where the surface rises to the proper level. Its surface has a maximum elevation of 149 feet a fraction of a mile southeast of Cohansey.

Fig. 26 is a section from Aldine south through Friesburg, Cohansey, Harmony, and Shiloh, and shows the relations of the Bridgeton west of Cohansey Creek. The section is along the divide between the Cohansey and the Delaware drainage. The surface of the formation declines a little to the southward, and its base declines from 120 at Aldine to 80 or so at Shiloh, a slope of about 3 feet to the mile. Its thickness here is greater than in most other places, being as much as 30 feet in many places.

Fig. 26 represents the Bridgeton as terminating to the south, just south of Bowentown, at an elevation of about 80 feet, along

the line of an abrupt scarp which overlooks Delaware Bay. It is evident that the material did not terminate this way originally. Its original slope, continued southward, would carry it down to an altitude of about 40 feet near the shore of the present bay, and its original southward extension has probably been removed by erosion.

The scarp from Port Norris to Salem was doubtless developed in post-Bridgeton time.

BETWEEN COHANSEY CREEK AND MAURICE RIVER.

Distribution.—This area lies between Daretown and Elmer on the north and Dividing Creek and Newport Station on the south. The Bridgeton formation covers the higher parts of this divide generally, especially at the north (north of Bridgeton and Rosenhayn). To the south it is more patchy, where smaller continuous areas of the original divide remain. The short tributaries of Cohansey Creek have cut through the formation near the main valley only, while the larger tributaries of the Maurice River have dissected it much more extensively. This is partly because of the greater size of the Maurice River and its tributaries, and partly because of the lesser original thickness of the formation in the basin of this stream.

At the north, the base of the formation has an elevation of 110 to 120 feet, but it declines to about 90 feet or a little less in the latitude of Bridgeton, and to 60 feet or so at Dividing Creek Station.

Fig. 27 shows the general relations of the formation in this region, or, more exactly, from Barnsboro to Port Norris, along the line passing through Centerton, Rosenhayn, Carmel, Center Grove, and Dividing Creek. From Union Grove southward, the Bridgeton appears in isolated areas only, capping the divides. Had the section been located west of Elmer, through Deerfield and Woodruff, more of the formation would have appeared.

The section shows that the base of the Bridgeton is marked by slight irregularities, but the great fact is its decline to the southward from about 140 feet in the vicinity of Elmer, to 60

or 70 feet at Dividing Creek, a slope of 2 to 3 feet per mile. This decline is slightly less than that to the southeast.

The most notable irregularity of the formation, apart from the irregularity of base at Barnsboro, appears in the 124-foot hill south of west of Carmel, where the formation, as mapped, occurs higher than in its surroundings. The relations in the 124-foot hill here are similar to those in the 176-foot hill at Richwood, except that at the latter place the base of the formation is not higher in the hill than about it, while at Carmel it is. It may be that the gravel about the 124-foot hill at Carmel, mapped as Bridgeton, is really older. The irregularity of base, however, even regarding the gravel and sand about the hill as Bridgeton, is no greater than in some other places.

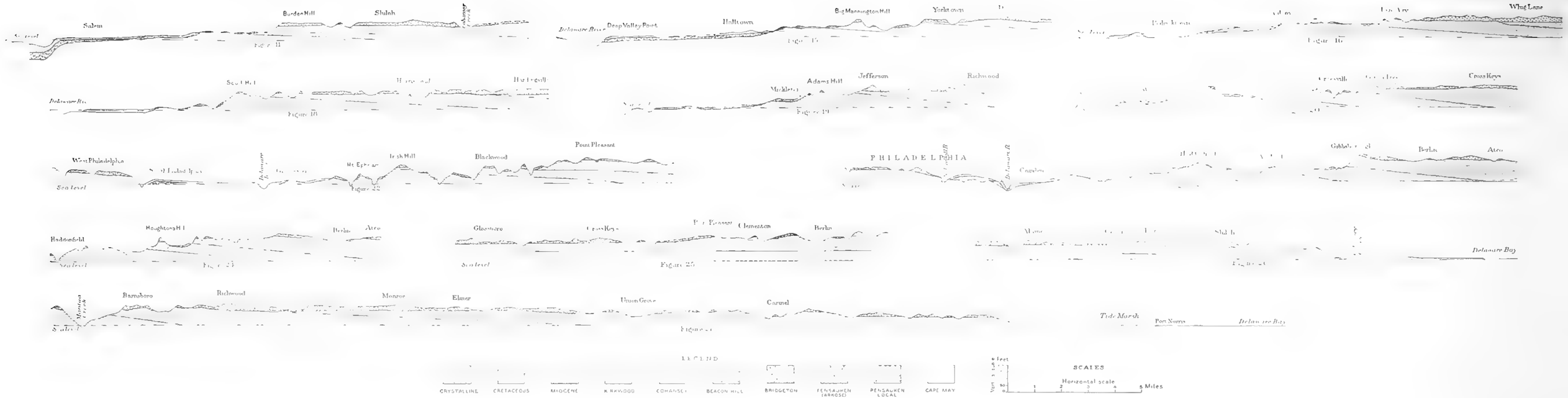
The formation appears to have its maximum thickness in the vicinity of Richwood, where erosion has been least; but its greater thickness here does not necessarily mean greater thickness originally.

Exposures.—The Bridgeton is well exposed in the vicinity of Aura (formerly Unionville), Harding, and Monroe. Still Run (near Aura) has removed much of the formation, and the remnants are thin, coarse gravel being common. It is probable that the coarse material was in the base of the formation originally.

There are gravel pits west of Monroeville, and exposures are found along the stream north of the village. The stream bank shows the base of the Bridgeton at an elevation of about 110 to 115. The gravel in this region is rather loose for the Bridgeton, and contains some shale.

A mile west of Monroeville, a pit shows 9 feet of Bridgeton, the upper 2 feet being gravel, sand, and loam, and the lower 7 feet highly colored compact gravel with some sand. Large pebbles and cobbles are rare, though present. Quartz and chert make up the body of the gravel, but there are some pieces of sandstone and a little shale.

Half a mile south of Monroe Station the Bridgeton is only 3 to 5 feet thick, and overlies glass sand. A mile southwest of the station there are several bowlders, one of "bull's head" type 1½ feet in diameter.


Salem
Burden Hill
Shiloh
Figure 11
Deep Valley Point
Hall town
Big Mannington Hill
Yorktown
Figure 12
Wing Lane
Figure 13
Scott Hill
Figure 14
Adams Hill
Jefferson
Figure 15
Cross Keys
West Philadelphia
Mt Ephraim
Irish Hill
Blackwood
Point Pleasant
Figure 22
PHILADELPHIA
Gibbstown
Berlin
Atco
Haddonfield
Houghtons Hill
Figure 23
Glassboro
Cross Keys
Point Pleasant
Clementon
Berlin
Figure 25
Delaware Bay
Barnsboro
Richwood
Monroe
Elmer
Union Grove
Carmel
Figure 27
Tide Marsh
Port Norris
Delaware Bay
LEGEND
CRYSTALLINE
CRETACEOUS
MIOCENE
KIRKWOOD
COHANSEY
BEACON HILL
BRIDGETON
PENSAUKEN (ARKOSE)
PENSAUKEN LOCAL
CAPE MAY
SCALES
Horizontal scale
Miles

The Bridgeton is well exposed in the vicinity of Elmer, particularly along the stream south of the village. In Jones' pit, west of Elmer, red shale is abundant in the gravel, but there is much less of it in the exposures south of Elmer. Coarse material at the base of the formation is common here, and in many places carries bowlders 1 to 3 feet in diameter.

There are several gravel pits in the vicinity of Palatine, especially along the bank of the stream, and in the vicinity of Upper Neck, on the east side of Muddy Run. Good exposures are to be seen, also, about Centerton and Finley. At the latter place there is a large pit on the railroad showing 20 feet of Bridgeton gravel and sand, overlying the Cohansey sand which carries laminæ of clay.

About Rosenhayn, a little Bridgeton gravel and sand overlie the Cohansey clay, which is here used for brick. A mile east of Rosenhayn, the railway cut at 90 feet shows Bridgeton over Cohansey. The former carries bowlders 1 to 2 feet in diameter, crystalline rock and sandstone both being represented.

Other exposures occur in the 134-foot hill southwest of Carmel, and in the vicinity of Gouldstown and Fairton. The sand and gravel are cemented in some places. The Cohansey, parts of which are of coarse sand in this vicinity, is sometimes hard to distinguish from the Bridgeton.

Near Cohansey Creek, the Bridgeton has been largely removed, but the coarser materials which characterize its base remain in abundance on the surface. Some of them are large. Two miles south of Fairton there is a bowlder of quartzite 2 x 2 x 5 feet, and bowlders of Miocene quartzite are common.

In the vicinity of Center Grove it is difficult, if not impossible, to distinguish the Bridgeton formation from the Pensauken. About Cedarville, arkose gravel and sand, probably Bridgeton, overlie the glass sand of the Cohansey formation. The gravel and sand have the general constitution of the Bridgeton, with the bed of coarse gravel or cobbles at the base in many places. A mile south of Cedarville there is a large glass-sand pit (Cohansey) at a level of 30–40 feet. This has a cover of 3 to 8 feet of sand younger than Bridgeton, and in contrast with it.

Many of the shallow exposures of this area show a sandy surface, with gravel below, but they do not go below the zone of weathering, and are therefore not very instructive.

Other exposures of the Bridgeton occur west of Dividing Creek Station, along the railway and northeast of the station, where the sand and gravel are cemented in places. Bits of gneiss occur in the conglomerate. Other exposures appear in the vicinity of Baileytown and Buckshutem, where bits of shale and gneiss may be seen with the arkose sand. Another good exposure is found 2 miles south of Millville, where there is a deep pit worked for "core" sand. The upper part is Bridgeton and the lower part Cohansey, the two not being easily distinguished. Other good exposures occur in pits a mile southwest of Millville, on the Cedar Grove road (Fig. 28), and another at Mulford's Pit, less than a mile south of the last. Sixteen feet of Bridgeton material was here exposed. Extensive working had allowed the accumulation of bowlders in the bottom of the pit. They ranged from 1 to 4 feet in diameter, and all were of sandstone and quartzite. The gravel here contained pebbles of clay.

BETWEEN MAURICE RIVER AND GREAT EGG HARBOR RIVER.

Between Maurice River and Manantico Creek.—The largest areas of the Bridgeton in this area appear on the uplands about Vineland, mostly above an elevation of 90 feet. The formation here is covered with eolian sand in many places. As the streams cut down through it into the Cohansey beds beneath, abundant sources of sand for the wind to transport were opened up. The smaller areas of the Bridgeton are more commonly covered by sand than the larger ones.

Numerous gravel pits and road cuts are found in this vicinity. In South Vineland there are pits opened for clay and glass sand, both of which are from the Cohansey; but over the sand and clay there is Bridgeton gravel and sand in most places, ranging up to 12 feet in thickness.

The general relations of the Bridgeton here are the same as at Downer, 15 miles to the north, and its constitution is essen-

Fig. 21.

Bridgeton gravel overlying glass sand near Downer Station, Gloucester County. Note the cobble bed at the base of the Bridgeton, and the deep pocket of gravel extending down into the glass sand.

Fig. 28.

Bridgeton formation near Millville, Cumberland County. Note the general fineness of the material.

tially the same, except that bits of shale and crystalline rock become fewer to the south, and the gravel becomes finer. The basal bed of coarse material is generally present.

The base of the formation here has some irregularities of a small sort. Thus south of South Vineland and east of Clayville, at the clay pits of the Globe Fireproofing Company, the surface of the Cohansey formation was seen stripped of the Bridgeton which once overlay it. The surface of the clay was marked by numerous depressions, some of which were like shallow gullies, and some were shallow depressions without outlets. Their forms suggested scour holes developed by running water, or, in some cases, depressions made by the overturning of trees. There are irregularities of other sorts, indicated by the fact that the altitude of the base of the Bridgeton varies 30 feet or more within the distance of a mile. This was seen in the vicinity of Clayville. Irregularities of base were also observed about Millville.

Between Manantico Creek and Manumuskin Creek.—A small area of the formation appears 2 miles southwest of Richland, a larger area on the divide between Hanges Bridge and Bennetts Mill, and several smaller areas on the summits south of Cossa Boone's Branch. The surface of the formation declines from a maximum of 120 feet at the north, to 70 at the south, and the decline of the base is from about 90 feet at the north to 60 feet at the south. The slight exposures show no distinctive features. The Cohansey sand in this vicinity is cemented in many places.

Between Manumuskin Creek and Tuckahoe River.—The Bridgeton appears on the divide between these streams most of the way from Richland to the latitude of Fries Mills. Farther south there are smaller areas on the upland east of Manumuskin and Bricksboro. As in the preceding cases the altitude is greatest at the north and least at the south, the decline being from about 90 feet at the north to about 50 feet at the south. About Richland and Doughty's the formation is orange-colored sand and gravel, with occasional cobbles, cemented in some places. The surface of the formation is more or less covered with eolian sand.

South and southeast of Bennetts Mills there are exposures at 70 to 100 feet. The material is generally more sandy than typical Bridgeton material farther northwest, though normal for this region.

At Hesstown, 7 miles southeast of Millville, there is an exposure in the 94-foot hill, showing arkose sand and gravel, with a cobble bed at the base.

Between Tuckahoe River and Egg Harbor River.—Between these streams the Bridgeton formation covers the low uplands, ranging in elevation from 70 feet or so near Mays Landing, to 40 feet, 3 miles north of Tuckahoe. South of Walker Forge, between South River and Stephens Creek, there is a considerable area of the formation, well exposed in the 71-foot hill south of the Forge. The base of the formation has an altitude of about 60 feet, and is cemented to conglomerate to some extent. Numerous other exposures occur on the road from Walker Forge to Estellville. They show repeatedly a thin cobble bed at the base, cemented in some places.

Southwest of Estellville there is a considerable area of Bridgeton on the divide between Tuckahoe River and Stephens Creek, and between Tuckahoe River and Pole Bridge Branch, centering about Russia. The gravel of this area is more compact and loamy then in the area to the north; otherwise it is essentially the same. That is, quartz and chert are the dominant materials, with cobbles 3 to 6 inches in diameter abundant in some places and rare in others. The gravel is cemented locally.

The general relations of the Bridgeton in this region are shown in Fig. 29, which extends from the vicinity of Green Tree to Tuckahoe.[1] The relations are much like those shown in Fig. 5. The thickness of the Bridgeton along the line of Fig. 29 is nearly uniform, but slightly greater at the northwest, near Green Tree.

The formation is well exposed at Buck Hill, about 3 miles north of Tuckahoe. The section is 6 to 12 feet deep, and the material coarse, orange-to-brown sand of arkose type, with scattered pebbles and beds of gravel. A bed of coarse gravel

[1] Figures 29, 30, 32, 33 are shown on Plate B, facing page 54.

lies at the base, on the Cohansey sand. Bowlders up to 3 feet in diameter on the floor of the pit apparently came from this basal bed. The largest bowlders are of brownish sandstone, of a type common throughout southern New Jersey.

The low altitude of this gravel and sand at Buck Hill raises the question whether it is not younger than Bridgeton. So far as its position is concerned, it might be Pensauken, or even Cape May; but at this locality, there are slabs of shale, even up to 2 feet in diameter, at the base of the formation, in precisely the same relations as at Folsom. This material, in this position, is so distinctive as to point strongly to its correlation with that at Folsom. Similar materials have never been found in the Cape May formation, or in the Pensauken formation southeast of the Amboy-Bordentown-Delaware valley lowland, if present correlations are correct.

The character and condition of the Triassic slabs at Buck Hill is such as to preclude the idea that this material has been reworked since its deposition. The general character of the formation is such as to rule out the Cape May formation at sight. This youngest of the Coastal Plain formations is everywhere composed of fresh, undecomposed material, whereas the decayed condition of everything that will decay is conspicuous at Buck Hill. Furthermore, the altitude of the gravel at Buck Hill is in keeping with the altitude of the Bridgeton to the northwest where it is characteristically developed. The same formation occurs at various intermediate points at harmonious levels, as at Russia, Doughty's, Richland, Newtonville, and Williamstown. In other words, if we project a line from Cross Keys at 150 feet, to Buck Hill, at 40, it will correspond closely with the base of the Bridgeton at all intermediate points.

Between the headwaters of Maurice River and Great Egg Harbor River.—Maurice River has its source near Glassboro and Cross Keys and flows to Delaware Bay at Port Norris. Great Egg Harbor River has its source a few miles farther northeast, near Berlin and Williamstown. In the area between the upper parts of these drainage systems, north of the headwaters of the Manantico and Manumuskin creeks, there are

considerable areas of the Bridgeton formation, as about Williamstown, at elevations above 140 feet, about Blue Bell at elevations above 120 feet, about Newtonville at elevations above 100 feet, about Richland at elevations of about 90 feet, and at lower elevations to the southeast.

At Williamstown a gravel pit at an elevation of 160 feet, on the north slope of the 164-foot hill in the northwest part of the village, shows 10 feet of gravel. The structure of the upper part is very irregular, but the lower part is well stratified in nearly horizontal beds. The lower part is arkose, coarser than the upper part, and contains less loam. Pebbles and bits of rock more than 1½ inches in diameter are rare, though occasional cobbles are present. Shale was not seen, but there are pieces of crystalline rock of the Philadelphia gneiss type (mainly of quartz and mica).

South of Williamstown, there are numerous shallow pits and cuts which show gravel and sand similar to that at Williamstown, but shale and crystalline rock are not seen, and from the habit of the formation would not be expected in such shallow exposures as most of those of this region. The base of the gravel, the horizon in which these constituents are most abundant, is rarely seen. Coarse material of the size of cobbles is rather common in spots, as east of Janvier.

The base of the gravel was seen at several pits between Williamstown and Richland, with the Cohansey sand below. The coarse gravel and cobbles at the base are present in many places, but, as a rule, without shale and crystalline material.

About Richland, there are numerous exposures in cuts and pits. The Southern Railway of New Jersey makes a cut 10 feet deep, showing orange-colored coarse sand, with seams of gravel and occasional cobbles or larger pieces of rock.

From the main divide along which the section shown in Fig. 29 is taken, the Bridgeton cap extends out over some of the minor divides between tributary streams. It also caps certain isolated hills or small areas set off from the main divides by erosion. One of these minor divides extends east of Richland, between Deep Run and South River, both tributary to Great Egg

Harbor River. Others lie between South River and Stephens Creek, and between the last and Tuckahoe River.

On the divide east of Richland, between Deep Run and South River, the Bridgeton is somewhat wide-spread at an elevation ranging from about 100 feet at Richland, to about 60 at Emmelville. In the same distance, the base of the formation declines from 80–85 feet to 55–60.

Exposures near Emmelville show 4 to 6 feet of gravel similar to that at Williamstown, except that it is more commonly cemented by iron oxide. The material is, indeed, quarried as much as dug. No shale or crystalline rock bits were seen here, and the correlation of the material with the Bridgeton is not made with great confidence.

The divide between Richland and Mays Landing shows a few exposures deep enough to be significant. The railway cuts show but a thin remnant of the Bridgeton. What appears to be the basal part of the formation is partly cemented to conglomerate which is locally in place and locally broken and displaced. The Cohansey appears to be but little below the surface.

Between Buck Hill and Cross Keys, shale and bits of crystalline rock are not seen in many places, though exposures are not rare in the vicinity of Russia, Richland, Newtonville, and Williamstown. These same materials are found on both sides of the line of the section, as at Downer, Folsom, and Millville.

If the section along the line of Fig. 29 be considered, the altitude of the surface of the formation ranges from 177 feet at Cross Keys, to 56 feet at Buck Hill. This represents a slope of about 4 feet a mile for the upper surface along this line. The base of the formation is more regular than the surface, but the general slope is in the same direction and about the same in amount. At Cross Keys, the base has an elevation of about 150 feet, and at Buck Hill of about 40 feet. The irregularities of base are such as would be expected from deposition on a surface of slight relief, developed by stream erosion.

BERLIN TO ATLANTIC CITY.

Distribution.—Fig. 30 shows the relations from Berlin southeast to Atlantic City. The section is extended northwest of Berlin, and takes in Houghton's Hill, which is somewhat out of line. The line of the section is along the divide between Mullica River and Great Egg Harbor River, where remnants of Bridgeton are considerable. The formation has been removed from the basins of these streams, except on the crests of isolated hills; but the remnants are so disposed as to leave no doubt that they are parts of a once continuous formation (p. 64).

About Hammonton, the base of the formation has an elevation of about 110 feet, but as everywhere else, it declines to the southeast. At Elwood its base is down nearly to 80 feet, and at Egg Harbor City nearly 20 feet lower. Between Hammonton and Egg Harbor City, it is found on divides only, and covers a relatively small part of the total area. It is well developed about Hammonton, especially to the south, in a small area at Banard Station, and on the more conspicuous elevations east of Da Costa, and over much of the area between Elwood and the western border of Egg Harbor City. Small areas occur 3 or 4 miles northeast of Elwood. Another small area to be mentioned is that southwest of Folsom, at an elevation of about 90 feet. In much of this area the formation is thin, and represents the base of the formation only.

Constitution.—Lithologically the formation is a unit from Berlin to Pleasantville, though not without variations. The coarse arkose sand, the bits of Triassic shale and crystalline rock, and the structure remain much the same throughout; but the distinctive red shale and the bits of crystalline rock become less abundant to the southeast. They become so scarce, indeed, that they do not appear in every exposure, especially if the base of the formation is not seen. It is to be remembered that bits of shale and crystalline rock are rare at some points well to the west, as at Williamstown Junction and Blue Anchor. In general, too, the Bridgeton material becomes finer to the southeast.

Exposures.—Good sections have been seen in the railway cut at the sanitarium near Hammonton, where the distinctive features of the formation are well shown, and in the railway cut at Folsom, 3 miles southwest of Hammonton. At the last locality, the foreign constituents (shale, schist, etc.) are especially abundant, and in large pieces (Fig. 9).

Exposures are common east and south of Hammonton in gravel pits and road cuts. Many of the cuts are in the Cohansey sand beneath the Bridgeton, rather than in the Bridgeton itself. In some of the pits, only the upper part of the Bridgeton is exposed, because this part is more gravelly than that below, and more compact by reason of its content of loam.

At Elwood the exposures show the same features with a coarse layer at the bottom at many places. A good exposure was seen 1½ miles northeast of Elwood, on the road to Batsto, in the 121-foot hill. Here 5½ feet of compact gravel of quartz and chert overlay 2½ feet of loamy gravel.

About Egg Harbor City and farther east, the separation of the Bridgeton formation from the Pensauken becomes uncertain, for the gravel and sand concerned sink to low levels and are well exposed in but few places.

In the vicinity of Pomona and Pleasantville, there are large areas of gravel with greater thickness, which are perhaps Bridgeton. There are good exposures in road-gravel pits 1 and 2 miles southeast of Pomona Junction, and also on the P. and R. R. R., a mile north of Pleasantville, and near Farmington Station. The exposures between Pomona and Pleasantville show 5 to 10 feet of Bridgeton material. In its general character it is typical of the formation, except that shale and crystalline material are wanting. The abundance of soft cherts is one of the features which suggest its Bridgeton, rather than Pensauken age. This chert must have been hard when deposited, and the decay is subsequent. The upper part of the formation here has more gravel and loam than the lower part, and less sand. The stratification is much more distinct and more regular in the lower part than in the upper. This point, alone considered, suggests a marine, rather than a fluviatile origin.

Base.—Northwest of Berlin, the Bridgeton base has an elevation of about 200 feet. Thence it declines southeastward to 160 feet at Wilton, 140 feet at Blue Anchor, 110–120 feet at Hammonton, about 100 feet at Da Costa, 80 feet about Elwood, and 60–70 feet at Egg Harbor City and Pleasantville.

The correlation of the Bridgeton at the southeast is somewhat uncertain, and its separation from the Pensauken may be questioned; but the decline from Berlin to Elwood, if continued, would bring the base of the formation down to the level indicated, at Pleasantville. The constitution of the sands and gravels at the higher levels near Pleasantville is consistent with this interpretation. If the gravels and sands of the higher levels about Pleasantville are Bridgeton, the base of the formation declines about 150 feet in 36 miles, giving it a dip of a little more than 4 feet per mile.

The base of the formation shows some irregularities, but they are of a small sort, and in keeping with those farther northwest.

THE WOODMANSIE PHASE.

Several cross sections from northwest to southeast, across the Coastal Plain, illustrate the general relations of this phase of the formation.

ARNEYS MOUNT TO TUCKERTON.

Distribution.—The area through which this section (Fig. 32) runs is mostly in the basins of Mullica River and Rancocas Creek, the two largest streams of the Coastal Plain in New Jersey. The area from Arneys Mount to Apple Pie Hill (near Harris Station) is in the drainage basin of Rancocas Creek, while the area southeast of Apple Pie Hill is in the basin of Wading River, a tributary of the Mullica River. The section is extended to the vicinity of Kinkora on the Delaware.

The conspicuous features of the section are (1) the broad lowland to the northwest, near the Delaware, (2) Arneys Mount and Apple Pie Hill, and (3) the upland at Munion Field near the ocean.

Arneys Mount is capped with Cohansey sand. Apple Pie Hill has a few feet of gravel, which is regarded as a remnant of the Beacon Hill formation. The gravel is of quartz and chert, in proportions of about 4 to 1, with a little sandstone and quartzite. If the Beacon Hill formation once covered Arneys Mount, as it probably did, it was at a level higher than the top of the present hill. Scattered pebbles of Beacon Hill type on the crest of the hill suggest such a former covering.

A plain from Apple Pie Hill (208 feet) to Bear Swamp Hill (165 feet), and to another 147-foot hill to the southeast, would, if carried northwest, have an elevation of about 250 feet at Arneys Mount (20 feet above its top). This probably represents about the appropriate level of the former Beacon Hill cap here. Carried southeastward, such a plain would have an elevation of 140 to 160 feet at Munion Field, and this is probably the approximate Beacon Hill level of that region.

Fearings Hill (about 2 miles northwest of Fountain Green) has about the same altitude as Houghtons Hill. Its gravel cap has the same topographic relations as the gravel on Houghtons Hill (Fig. 24), Point Pleasant (Camden County) (Fig. 22), and Jacobstown (Fig. 33), and is referred to the Bridgeton formation. The gravel itself is not of such a character as to give especial force to this correlation.

Northwest of Apple Pie Hill (South Park) there are gravel beds 4 to 10 feet thick, at an altitude of about 140 feet, which probably are Bridgeton (possibly Pensauken). The same may be said of the gravel about Munion Field at elevations of about 120 feet.

Some of the features of these gravels which seem difficult of explanation are probably connected with the shifting of the main divide of the region from near Arneys Mount, to its present position, near Apple Pie Hill.

Constitution.—The gravels at South Park, at an altitude of about 140 feet, and in the vicinity of Bear Swamp Hill, at 120 to 160 feet, consist mainly of quartz and chert, but they contain bits of ironstone, which seems to rule them out of the Beacon Hill formation. The absence of the ironstone, so far as ex-

posures show, and the abundance of the soft chert at Apple Pie Hill, together with its topographic position, seem to place the gravel of that place with the Beacon Hill formation, though the correlation is less decisive than could be desired.

In the Beacon Hill formation the cherts are weathered characteristically. The chert pebbles seem to be made up of an irregular network of harder and more insoluble material, filled in with less durable material. On weathering, the less resistant parts become whitish powder, while the skeleton remains hard. At the surface, the decayed part is carried away and the skeleton remains. In secondary gravels derived from the Beacon Hill, the old networks are more or less broken and worn. Occasional fossils in the chert point to its origin from Devonian formations.

The quartz in the gravel is vein quartz largely. On weathering, the pebbles develop a columnar structure. This may go so far that the little columns separate from one another. Some of the pebbles may be crushed in the hand, even when their outer forms are still perfect. In gravels derived from the Beacon Hill gravel, there are splinters from these pebbles of columnar structure, but decayed pieces of quartz are much less common than in the original Beacon Hill formation.

In the vicinity of Tuckerton, the section shows gravel and sand interpreted, though not without reservation, as Pensauken. No facts concerning these sands and gravels are known which would preclude their deposition by streams or by the ocean. Since they were deposited, the ocean has doubtless encroached on the shore, carrying away the shoreward part of the formation as originally laid down within the limits of the State.

Correlation.—From the foregoing it is apparent that the basis for correlating any gravel and sand along the line of this section with the Bridgeton formation, is rather insecure. Such correlation must be based on topography more than on anything else. It is to be noted that the possible Bridgeton beds at 160 feet at Bear Swamp Hill, and at 126 feet at Munion Field, are considerably nearer the ocean than the areas of Bridgeton at corresponding levels in other sections. So far forth, this would suggest the greater (pre-Bridgeton) age of these gravels.

The highlands at 140 to 160 feet, near Tuckerton, are nearer the ocean than areas of similar altitudes to the west. But if the sea has encroached notably on the land in this vicinity, the deposits at Munion Field are nearer the shore than they were at some earlier time. If the Delaware be taken as the base line of comparison, Munion Field is 38 miles from it, while Waterford, Williamstown and Glassboro, where the Bridgeton formation has a similar altitude, are less than half as far from the river. The Bridgeton (?) gravel at 140 feet at South Park, near Apple Pie Hill, is about the same distance from the Delaware as the Bridgeton gravel at 140 feet near Williamstown, Glassboro and Elmer. If, in pre-Bridgeton time, the Mullica River had its head near Arneys Mount, and developed a broad valley plain sloping to the southeast, the 144-foot level at South Park would be the appropriate level for gravel accumulation. But if the 144-foot level is the proper Bridgeton level at South Park, 140 feet at Munion Field would be too high. This tract appears to have been a relative highland in Bridgeton time, and to have escaped much deposition above 120 feet. Such gravel as there is here at the higher levels may have been left in the course of the degradation of the region from an older and higher level.

ELLISDALE TO BARNEGAT.

The section shown in Fig. 33 is nearly parallel to the last, but is along the divide between Mullica River and Toms River at the southeast, and across the basins of Crosswicks Creek and Rancocas Creek at the northwest. The section is extended northwestward through Allentown to the vicinity of Pennington. It brings in some points which are somewhat out of line, and omits many minor irregularities of surface; in other words, it is somewhat generalized. The topographic distinctness between the Pensauken gravel and the Bridgeton gravel is well shown in this section (Allentown and Jacobstown).

The conspicuous features of the section are the highlands in the vicinity of (1) Ellisdale and Jacobstown, and (2) Woodmansie and Old Half Way.

The 229-foot hill at Ellisdale corresponds with Arneys Mount of the preceding section, while the highland at Woodmansie corresponds in some sense with Apple Pie Hill. In keeping with these suggested correspondences, the gravel at Woodmansie is correlated with the Beacon Hill formation, while that southeast of Woodmansie, that at Millville (Ocean County), and that at Barnegat, appear to be younger.

The top of the hill at Ellisdale is Kirkwood or Cohansey sand. It is below the level at which the Beacon Hill formation would be expected in this immediate region. The base of the Beacon Hill gravel is at 360 to 375 feet above Crawfords Corner, 340 to 360 feet at Clarksburg, and 330 feet at Stone Tavern. If the base of the formation continued to decline southwestward at this rate, it should lie at about 300 feet at Ellisdale, and 280 feet at Arneys Mount (see p. 51). If the proper elevation for the Beacon Hill gravel at Ellisdale and Arneys Mount be estimated from remnants to the southeast, the result is about the same. The Ellisdale Hill is also too low for the Bridgeton in this region, for while the data are imperfect, the restoration of the pre-Bridgeton surface as a plain ranging from 250 feet at Ellisdale, to 200 feet at Woodmansie and 150 feet at Barnegat, seems to be indicated from such data as bear on the point.

The Ellisdale-Jacobstown elevations are parts of the old divide between the Delaware drainage and the ocean drainage. The headwaters of Crosswicks Creek have worked back, capturing the tributaries of the streams that formerly flowed to the ocean, and leading them by a circuitous route through the Cream Ridge gap, westward to the Delaware.

Topographically, the hills at Ellisdale and Jacobstown go with the Clarksburg hills, and the gravels at Jacobstown are, therefore, the topographic equivalent of those at Glassboro and Daretown, and are older than the Pensauken formation.

Though the topographic equivalent of gravels at Glassboro, the gravels of Jacobstown are not arkose, and they contain detritus from the Cretaceous as well as from younger beds. Since the gravel at Jacobstown contains Cretaceous material, it must be assumed that the streams which deposited it (assuming

Figure 29

Figure 30

Figure 33

Figure 34 (continued)

it to be a stream deposit) flowed from the northwest to the southeast. These gravels are now 15 feet or so higher than the outcrops of the highest Cretaceous beds in the vicinity. At Ellisdale, a few miles away, the Cretaceous outcrops at altitudes up to about 200 feet. Outcrops of the same beds farther northwest would have been higher, and such outcrops northwest of Jacobstown (now worn much lower) may well have been the source of the Cretaceous material in the Jacobstown gravel, if streams flowed to the southeast from them.

From the present topography, it is inferred that Toms River once had tributaries reaching northwestward past Prospertown to Clarksburg. Either Toms River or Mullica River probably had branches as far northwest as Ellisdale at least. On the supposition that the drainage was to the southeast, it is therefore not difficult to account for the Cretaceous material in the Jacobstown gravel.

The gravel at 140 feet at Barnegat seems best correlated with the Bridgeton formation, and if this correlation is correct, the gravel a few miles south of Staffordville, at about 100 feet, may be Pensauken.

A few areas of gravel not on the line of the section merit notice. One of these is south of Jacobstown, where gravels which belong with those at Jacobstown decline to 170 feet or so at Springfield, and to about 150 feet at Fountain Green and Pointville. The gravel on Fearings Hill, west of Springfield and Fountain Green, is an outlier of the larger areas at these places. The gravel at Fearing Hill is regarded as a local phase of the Bridgeton, the same as that at Jacobstown.

West of Colliers Mills, there are areas of gravel at altitudes ranging from 160 feet to 208 feet. The 208-foot hill is 1½ miles northwest of Colliers Mills on the Hornerstown road, and the 160-foot area a mile south of Colliers Mills. These remnants are along the divide between the headwaters of Toms River and Crosswicks Creek. The gravels here may be parts of a once continuous sheet, or remnants of deposits on an old valley plain.

Bordens Mill Branch, flowing past Colliers Mills, is a tributary of Toms River, and appears to have headed formerly in the

Clarksburg hills, and to have flowed through Prospertown, Archers Corner, and thence to the sea, as now. Ivanhoe Brook, which heads north of Prospertown, is perhaps the original head of Bordens Mill Branch, but it is now the head of Lahaway Creek, tributary to Crosswicks Creek. In Bridgeton time, the drainage probably went from Clarksburg south by way of Ivanhoe Brook, Prospertown, and Colliers Mills, to Toms River. When Crosswicks Creek cut across the marl highland at Cream Ridge, and entered the region of Hornerstown and New Egypt, the drainage of Lahaway Creek and Ivanhoe Brook was diverted to the Delaware. The gravel west of Colliers Mills at an elevation of about 200± feet, was probably deposited by the stream which followed the course of Bordens Mill Branch in Bridgeton time, when the drainage from the Clarksburg region flowed to Toms River.

The gravel west of Colliers Mills is of local trashy material derived from the Beacon Hill and Cohansey formations. It contains nothing which can be referred confidently to the Cretaceous. The streams of the time had not yet cut through the Miocene of the Clarksburg region, and so had not access to older formations.

HIGH LEVEL GRAVEL AT HEAD OF WOODS.

From Head of Woods southeast to Whitings, there is a series of hills ranging from 160 to 200 feet in height, along the divide between Toms River on the one hand, the Rancocas and Crosswicks creeks on the other. Just south of Colliers Mills, at Head of Snag, there is a gap in this divide, at the 130-foot level. This is probably part of a valley occupied by a stream for a considerable time after the epoch of Bridgeton deposition. It is probable that the drainage from the vicinity of New Egypt, and possibly from the vicinity of Jacobstown, once went eastward by Head of Snag to Toms River, and that the drainage did not assume its present course until long after the Bridgeton formation was deposited.

At Boyds Hotel, near Whitings, there is a gap in the divide at the 150-foot level. This probably represents a portion of another old valley which extended far to the west or northwest.

The drainage of the region in the vicinity of Browns Mills, and possibly as far west as Arneys Mount, may once have gone east by way of Buckingham and Boyds Hotel, to Toms River.

This range of hills has but little gravel (1 to 5 feet), and that on the higher elevations. It seems to represent the last remnant of a gravel bed which once covered the whole area, and which was deposited on a plain of erosion developed after the Beacon Hill epoch. The region is thought to have suffered a degradation of 50 to 75 feet after this epoch, for the Beacon Hill formation originally extended over the region from Whitings to Head of Woods, at a level which is now about 250 to 275 feet above sea level.

GRAVELS (BEACON HILL?) ABOUT WOODMANSIE.

In the vicinity of Woodmansie there are many patches of gravel at various high levels. To the northward, at Whitings, they are at elevations of 170 to 200 feet; just east of Wheatlands, at a maximum altitude of 201 feet; east of Woodmansie, in the vicinity of Old Half Way, up to altitudes of 213 feet; south of Old Half Way and southeast of Woodmansie, up to 208 feet; 3 miles southwest of Woodmansie, near the railroad, up to 204 feet. There is, therefore, a considerable area within 5 miles of Woodmansie where the surface rises to an altitude of 200 feet at many points. These higher lands are usually capped with gravel. Its depth is rarely more than 5 or 6 feet, though in occasional pockets twice this thickness is reached. It would appear that the region was once quite generally but thinly covered with gravel at the level of 200 feet, and that the gravel patches now remaining are but remnants. There are numerous gravel remnants at slightly lower levels, some of which, at least, have been displaced downward since deposition.

The correlation of these gravels is not clear. They seem a little too low for Beacon Hill and a little too high for Bridgeton. They are farther southeast than Whitings, where the Beacon Hill gravels might be a little lower than to the north and northwest. They may include deposits of both epochs, especially if the erosion between the two epochs of deposition was here but

little. The upper part of the later deposit may be as high as the lower part of the earlier.

Apparently the Woodmansie area has suffered almost the minimum of erosion since Beacon Hill time. More than any other tract in southern New Jersey, it seems to have been avoided by large streams, since that epoch. There seems therefore to be no adequate reason for excluding these gravels from either formation.

In Bridgeton time, the Woodmansie upland probably extended farther northwest than now, toward Mt. Misery; but when Rancocas and Crosswicks creeks got their heads into this region, they degraded their basins faster than the Mullica River and Toms River degraded theirs.

CLARKSBURG TO ISLAND HEIGHTS.

Location of section.—The section shown in Fig. 34[1] represents the general topographic relations along the divide between Toms River and Metedeconk River, the headwaters of which are close together in the vicinity of Charleston Springs. Metedeconk River was once a larger stream than now, for some of its headwaters have been captured by Manalapan Brook and Millstone River. Its earlier source was probably in the Perrineville hills.

The section is somewhat composite and diagrammatic. It passes through the 354-foot hill a mile north of Clarksburg, and thence southeast nearly to Cassville. Here the 257-foot hill and others at about 190 feet, a little out of line, are brought into the section. Near Cassville the section is offset to the northeast about 2 miles, and is then continued southeastward, parallel to the Metedeconk River to Seven Stars, near Lakewood. From Seven Stars, it follows a line roughly parallel with Toms River, to Island Heights and thence to Berkeley. Some minor details are omitted.

To the northwest, the section is carried to Disbrows Hill, Hightstown, Dutch Neck, and Princeton, and the Rocky Hill

[1] Figures 34, 35, 43, 44, 45, 46, 47, 48, 50, 51, 52, 53, 54 are printed on one plate, opposite page —.

range, for the purpose of bringing out the relations of the Pensauken formation.

In this section the Beacon Hill gravel appears at one point only, namely, in the Clarksburg hills, where its base has an elevation of about 360 feet. This alone would give little clew to the surface in the Beacon Hill time, but from the sections of Figs. 34 and 35 (p. 136) more is known of it.

On the Rocky Hill range there is a meager scattering of gravel at levels between 300 and 400 feet. These traces of gravel are in accord with the hypothesis that the Beacon Hill formation once covered the ridge.

Bridgeton base southeast of Clarksburg.—The data for the reconstruction of the Bridgeton base along the line of this section leave much to be desired. Southeast of Clarksburg there is a series of elevations ranging from 250 feet near Carrs Tavern to 96 feet at Island Heights. The gravels on the hills, which range from an altitude of 190 feet near Francis Mills to 160 feet at Cassville and to 150 feet in the vicinity of Lakewood, are regarded as most probably of Bridgeton age.

The volume of material near Lakewood is much greater than at the 190-foot level at Francis Mills. Its elevation at Lakewood is 150 feet, more or less. In constitution it is very unlike the gravel near Clarksburg, but very similar to that at Barnegat, which is like that of Hammonton and Vineland, except for the absence of shale and crystalline material. The Lakewood and Barnegat gravels are alike in coarseness, proportions of sand and gravel, structure (for example, the long, horizontal lines of pebbles seen in section), compactness, color, cementation, etc.

From Lakewood to Island Heights, the surface declines from 150 feet to about 50 feet at Toms River. Most of the surface is covered with gravel. It is doubtful if all of it is of the same age, but the differentiation of its parts, if its parts are different, is difficult. The gravel at the lower levels carries more ironstone, etc., and less soft chert, relatively, than that at the higher levels. It is possible here, in various cuts, to recognize about the same distinctions, with reference to constitution, that obtain in the Bridgeton, Pensauken, and Cape May elsewhere. It seems prob-

able that these several formations here overlap one another; that is, that they are more or less imbricated.

Bridgeton base northwest of Clarksburg.—To the northwest of the Clarksburg hills, there is difficulty in identifying the Bridgeton formation and in determining the level at which it should occur. Between Disbrows Hill and Rocky Hill (Fig. 34) is the broad lowland covered by the Pensauken formation. Northwest of the Pensauken area there is a tract near Princeton, more than 200 feet in elevation. This elevation stands in about the same relation to Rocky Hill that Disbrows Hill does to the Clarksburg hills.

At at elevation of about 220 feet in the vicinity of Lawrenceville southwest of Princeton, patches of gravel are found. They are too low to be correlated with the Beacon Hill gravel, and too high for Pensauken, and for these reasons are regarded as probably Bridgeton remnants.

Near Pennington, 7 miles west of Princeton, there are bowlders, gravel, etc., at elevations of 200 to 240 feet, and this level seems to represent a rather definite former plain of degradation. The bowlders are regarded as probable remnants of the Bridgeton cover which once overlay the region.

Near Disbrows Hill, the section shows lesser hills at 160 to 180 feet. These hills are in reality a little south of Disbrows Hill, but the section shows their proper relations stratigraphically and topographically. Their gravel caps may be Bridgeton or post-Bridgeton, and their correlation is open to question.

The pre-Bridgeton surface southeast of the Clarksburg hills appears to have had an altitude of about 200 feet and to have declined to the southeast. This plain of degradation was probably developed by streams 25 to 40 miles in length. Northwest of the Clarksburg hills the pre-Bridgeton plain was probably developed by the great river which flowed through the Amboy-Bordentown valley, and by its tributaries. If this is so, the plain developed by this master stream should have been lower than the plains to the southeast developed by many small streams. The Delaware now has its bed down to tide level up to Trenton, 100 miles or so from the ocean proper. The larger stream of earlier

times may have been near tide level still farther from the sea. The pre-Bridgeton lowland on the northwest side of the Clarksburg hills, therefore, may well have been lower than the corresponding plain to the southeast. Its level near Hightstown may be inferred from the facts set forth in the following paragraphs.

1. In the vicinity of Blackwood and Haddonfield, there was a considerable area near the Delaware in pre-Bridgeton time, 40 to 60 feet lower than the major divide at Berlin and Glassboro. This lower land appears to have been a lowland or rude terrace bordering the ancestor of the Delaware. If this stream was at tide level at that time, this bordering lowland could not have been very much higher.

The present remnants of this lowland, as located by the base of the Bridgeton, have altitudes of about 100 feet at Woodstown, 120 feet at Woodbury, and 130 feet at Haddonfield. If these figures indicate the rise of this old lowland to the northeast, a surface projected from Haddonfield to Hightstown in accordance with this slope, would have an elevation of about 200 feet at the latter place; but without further evidence, it would be unsafe to assume that the plain of Bridgeton deposition at Hightstown was at this level. The data, however, do indicate that the pre-Bridgeton lowland rose to the northeast from the Delaware.

2. The 200-foot divide in the vicinity of Freehold apparently goes with the 140-foot surface at Glassboro beneath the Bridgeton gravel, and appears to be a part of the same plain sloping southward.

The lowland along the Delaware, in the vicinity of Barnsboro and Blackwood was apparently 40 to 60 feet lower than the plain at Glassboro and Daretown, farther back from the main stream. Similar relations appear to have existed in the vicinity of Freehold, and the Hightstown plain was perhaps 50 to 60 feet lower than the Freehold plain at 200 feet. If the remnants of the pre-Bridgeton plain at Freehold are now found at 200± feet, the remnants of the pre-Bridgeton plain at Hightstown, if they exist, should be 50 or 60 feet lower.

By these two lines of approach, therefore, we seem to reach different conclusions with reference to the height of the Bridgeton plain at Hightstown.

Possible changes of level.—If the Glassboro phase of the Bridgeton formation is glacial outwash in part, it filled the broad valley from Amboy to Bordentown, and overspread the low divide below Berlin. On the lowland bordering the Delaware, some 50 feet of Bridgeton material accumulated, and 50 feet more on the divide at Glassboro. It would appear, therefore, that the Bridgeton material must have been something like 100 feet deep, at a maximum, on the lowland along the Delaware. The upper surface of the deposit at Haddonfield must have been at a level which is now somewhere about 200 feet above the sea, and there should have been a harmonious gradient from Hightstown toward Haddonfield sufficient to allow the transportation of material, if it came by way of the Hudson, and if relative levels have not changed since. This would bring the Bridgeton surface at Hightstown up to the supposed pre-Bridgeton plain of erosion at Freehold, about 200 feet; but this level at Freehold did not receive the glacial outwash. Therefore we must infer either that the preceding hypotheses are incorrect, or that the relative altitudes of the Freehold and Glassboro regions have changed. Evidence of relative change is found in the fact that the Bridgeton formation, reaching an elevation of 200 feet (present) at Berlin, appears not to have reached the 200-foot areas at Freehold, though the latter place is some 50 miles nearer the assumed source of the gravel. Allowing for the necessary gradient, it would seem that the Freehold region should have stood 100 feet or so higher than the Berlin region at this time, in order to have escaped deposition.

From data about Berlin, it is concluded that that region stood 80 to 100 feet lower in Bridgeton time than now. If this was the case, the Freehold region might have had an altitude similar to that of the present.

It is difficult to conceive what the attitude of the region was in Bridgeton time, in order to meet all requirements. If the region near Hightstown and Freehold was elevated at the be-

ginning of Bridgeton time, so as to give a steep gradient to the southwest, such elevation should have affected the streams flowing from Freehold to the ocean, unless the coast were correspondingly farther out. If the streams flowing to the southeast were affected by such an elevation, they should have deepened their alleys; but we find no evidence that the valleys were so deepened at this time. If, on the other hand, the region about Berlin subsided while the region at Freehold remained 100 to 150 feet above tide, there might have been sufficient grade to carry material from Hightstown to Berlin.

A possible explanation of the difficulties is found in the position of the coast line in the Bridgeton period. The eastern coast suggests that it has been encroached upon by the sea in post-Bridgeton time. From Toms River north, it probably lay much farther east in the Bridgeton epoch than now. If the coast line were some 30 miles east of the present coast in the vicinity of Asbury Park and Long Branch, some of the difficulties would be met.

If we assume that the old pre-Bridgeton lowland, in the vicinity of Hightstown and Amboy, was below the present 150-foot level, the Bridgeton base was below the top of the Pensauken, and all hope of separating the two formations, on topographic grounds, is gone.

The difficulty, therefore, appears as follows: The material between Amboy and Trenton regarded as Pensauken has a maximum altitude (surface) of nearly 190 feet at Amboy and a minimum altitude (base) of 60 feet in the vicinity of Amboy and Sayreville. It has a maximum (surface) altitude of 130 or 120 feet in the vicinity of Trenton and a minimum (base) of 10 or 20 feet. The material, however, appears to be a unit throughout this entire area, and throughout this vertical range. If the gravels at elevations of 150 feet at Hightstown and those still higher at Amboy are Bridgeton, we have no means of demonstrating that all the gravels down to the 20-foot level at Trenton are not Bridgeton. This assumption would lead us into still greater difficulties south of Trenton.

On the whole, the evidence seems to suggest that the region in the vicinity of Hightstown must have been at or below what is now the 150-foot level in Bridgeton time, and that a plain at some such level at Hightstown corresponded to the 200-foot plain at Carrs Tavern, and the 150-foot plain at Lakewood.

HOMINY HILLS—MANASQUAN.

Location of section.—Fig. 35 is a section from Bonhamton north of the Raritan, to Manasquan, through Beacon Hill, Hominy Hills, and Allenwood, slightly generalized and simplified. It represents the general cross section of a belt a few miles wide, rather than a section along a line. The most conspicuous feature in the profile, as compared with preceding figures, is its relief. The hills appear high and steepsided, and the valleys deep and narrow. Comparing this section with Fig. 33, it will be seen that there has been greater erosion in post-Beacon Hill time in this region than in the vicinity of Woodmansie.

Beacon Hill deposits.—The highest elevation is Beacon Hill, with an altitude of 372 feet. It has a cap of gravel about 10 feet thick. Throckmorton Hill, in the Hominy Hills group, about 9 miles southeast of Beacon Hill, has a similar cap of gravel. Projecting a plane from the base of the gravel in Beacon Hill through the corresponding position in Throckmorton Hill, it will be found to pass over Manasquan at an elevation of 150 feet. If this be regarded as the base of the Beacon Hill formation, it indicates that the region about Manasquan has suffered notable degradation in post-Beacon Hill time. Extending the same plane northwest over the Amboy region, it has there an altitude of 400 feet. This would indicate a degradation of 200 to 300 feet in this region in post-Beacon Hill time, if the Beacon Hill formation once overspread this region, with its normal dip.

Pre-Bridgeton surface.—From the profile, it is seen that at Hillsdale there are areas of bare Cretaceous at an elevation of about 250 feet, and others at Barrentown at about 200 feet. Near Allenwood there are gravel-capped hills at 120 to 140 feet, and this gravel appears to be Bridgeton although there may be

some question as to this correlation. It is 8 to 9 feet thick, about 80 per cent. quartz and 20 per cent. chert. It is very like that of the Beacon Hill formation except for occasional bits of ironstone. Taylors Hill, near Hominy Hills, has a gravel cap at 180 feet, and this too, is regarded tentatively as Bridgeton. Other hills in the vicinity, at 130 to 140 feet, in the same relations as Taylors Hill, have caps of gravel interpreted as Pensauken.

These various levels are more or less discordant. Though levels at about 250 feet near Hillsdale and at 200 feet at Barrentown appear to be connected with the outcrops of certain beds of the Cretaceous, there are, in the same vicinity, other hills at about 200 feet of which the top is Miocene. It seems probable that the hills at about 200 feet near Barrentown go with the 140-foot levels at Allenwood.

Constitution of the Bridgeton.—The Bridgeton gravels of this region contain no material which can be identified as having come from the Cretaceous. The surface during the Bridgeton epoch was mostly in the Miocene and Cohansey formations, and they yielded the sand and gravel deposited here in the Bridgeton epoch. Cretaceous beds must have been exposed about Crawfords Corners, but there was little sedimentation there, or if there was, but little of it now remains.

In Pensauken time, on the other hand, the Cretaceous beds were extensively exposed, and the deposits of that epoch north of the Hominy Hills contain much material from that system. Some of the streams which flowed from the Cretaceous to the Miocene, carried sediments from the former out onto the latter.

The result was that the sediments which accumulated in the Bridgeton and Pensauken epochs in this region were quite different in composition. For instance, the gravels (Pensauken) which are found in Swimming River valley in the vicinity of Holmdel, at 140 to 170 feet, contain much material derived from the Cretaceous, and are regarded as Pensauken.

VICINITY OF BEACON HILL AND NORTHWEST.

In the region about Beacon Hill, there is very little gravel and sand which can be correlated with the Bridgeton. Eastward, near Chapel Hill, and in the Navesink Highlands, there is gravel at 200 to 220 feet which may be so correlated, but most of this material appears to have suffered but little re-working from some older formation, probably the Beacon Hill.

Northwest of Beacon Hill, the section, Fig. 35, is continued to Bonhamtown, but shows no certain Bridgeton. At Morristown, near Matawan, a small hill at 150 feet is shown with a cap of gravel. There is also gravel in a bench a few feet below the top of this hill (at 120 to 140 feet). The gravel at the lower level at Morristown is similar to the Pensauken material between Matawan and Freehold. That on the top of the hill is sufficiently different to suggest, but not to prove, their distinctness. Whether the gravel at the top and that on the bench belong together, or whether they represent Bridgeton and Pensauken, is uncertain.

The Browntown hills southwest of Matawan, with their gravel caps at about 200 feet, stand in much the same relation to Beacon Hill, as Disbrows Hill does to the hills at Clarksburg. The gravel caps of the Browntown hills, rather than the 150-foot hill at Morristown, may represent the true Bridgeton level for this region.

In the vicinity of South Amboy and Sayreville, there are considerable areas of gravel, the base of which is irregular. The lowest level of its base at Bonhamtown is about 60 feet, and the maximum altitude of its surface, near South Amboy, is nearly 190 feet. It is referred to the Pensauken, and will be described more at length later.

CHAPTER III.

THE PENSAUKEN FORMATION.

CONTENTS.

General Description.

SEQUENCE OF EVENTS.

Pre-Pensauken erosion.—After the deposition of the Bridgeton formation, conditions in the southern part of the State changed so that erosion succeeded deposition. The southwestern part of the State at least seems to have been somewhat higher than during the Bridgeton epoch, possibly a little higher than now during at least a part of the interval of erosion.

Some of the drainage lines, during this epoch of erosion, did not differ greatly in position from those of the present time, while others were notably different. One main line of drainage seems to have been from Raritan Bay to Trenton, and thence down the Delaware. This indeed seems to have been the course of the master stream of this part of the Coastal Plain. Streams from the north joined this master stream at various points between Raritan Bay and the present Delaware, and other streams doubtless joined it from the southeast and east.

The postBridgeton-prePensauken interval of erosion was a long one,—long enough for the development of a broad plain of erosion between Raritan Bay on the northeast and Salem on the southwest. This plain was about 20 miles wide at New Brunswick, and wider still to the northeast; 12 miles wide at Monmouth Junction, 15 to 20 miles wide from Trenton to Philadelphia, 10 miles at Chester, and 20 at Salem. Cretaceous formations underlie the larger part of this plain of erosion. The main divide of southern New Jersey lay but a few miles to the southeast of this broad valley, along the line connecting the Atlantic Highlands, Mount Pleasant, Clarksburg, and Berlin.

During the period of erosion which developed the great valley noted above, streams flowing southeast from the main divide of the southern part of the State developed broad valleys which are to be correlated with the Raritan Bay-Trenton-Salem plain; but the plains of these minor valleys were much less extensive and less well defined, and have been less carefully studied, and the

deposits made in them during the Pensauken epoch have not been clearly differentiated in most parts of the southeastern slope.

Pensauken deposition.—After the development of these broad valley-plains of erosion, conditions became such as to cause deposition upon them, and these deposits constitute the *Pensauken formation.* The principal part of the formation, and the part which is most distinctive, was deposited on the valley lowland between Raritan Bay and Salem. Contemporaneous deposits elsewhere were less extensive, less distinctive, and difficult of differentiation.

The conditions and the agents of deposition have been much discussed, and there is still difference of opinion concerning them. The chief opposing views are (1) that the plains of erosion referred to above were submerged, and that the deposition which followed was marine; (2) that the plains were not submerged, and that the deposits were fluvial; and (3) that submergence was partial, and that the deposits are partly marine and partly fluvial.

According to the interpretation of the formation which assigns to it a fluvial origin, its material was brought to the Raritan Bay-Trenton-Salem plain by drainage from the north. The principal contributing streams were the Hudson, the Raritan and the Delaware, or their predecessors. This view carries with it the hypothesis that Raritan River then flowed southward from the mouth of the present Millstone, up the valley of that stream, to the master stream in the Raritan Bay-Trenton valley.

On the hypothesis that the Pensauken deposits are terrestrial, they are thought to have been made at a time when the streams from the north bore the gravel, sand, etc., of the melting ice of one of the early glacial epochs. This view is based on the physical and lithological characteristics of the deposits. If this interpretation of the origin of the formation is correct, that part of it in the Raritan Bay-Bordentown-Salem valley is a sort of broad *valley train.* One of the difficulties of this interpretation is that the materials do not decrease regularly in coarseness down the valley as in a normal valley train.

As the main valley was aggraded, its tributaries were obstructed, and deposition in them must have accompanied deposition in the main valley. None of the streams tributary to the main valley from the south and east between Raritan Bay and Salem bore glacial waters, and hence the deposits they made in their valleys were of local debris, derived from their own drainage basins. The same was true of some of the small streams coming to the main valley from the north. At the same time, deposits were probably making in the valleys of streams flowing from the main divide of the Coastal Plain southeast to the Atlantic. The lower ends of these valleys were not being aggraded by deposits in just the same way that the lower ends of tributaries to the Raritan Bay-Trenton-Salem valley were, if the hypothesis outlined above be the true one. Furthermore, the streams flowing southeastward from the Coastal Plain divide were not laden with glacial debris, as were the main streams north of the main valley. The presumption is, therefore, that if the attitude of the land remained much as it was during the time of erosion just preceding, deposition in the valleys of the southeastward flowing streams was much less than that in valleys of streams carrying glacial debris.

If, on the other hand, the Pensauken formation is marine, its sediments being laid down during a time of submergence, the deposits in the valleys which led to the sea directly may have been more considerable. Even in this case, however, deposition of sediments brought in by streams not fed by glacial waters was probably less than that contributed by streams which came out from the melting ice.

The third view of the origin of the formation is hardly more than a combination of the other two. In this case, the proportion of the formation which is fluvial might be conceived to be very large or very small, or to be anywhere between these extremes.

After the deposits of Pensauken sands and gravels in the Raritan Bay-Trenton-Salem valley had reached a thickness which exceeded two score feet in but few places, deposition ceased. This may have been because the area became somewhat higher,

giving the streams a greater gradient, or because the streams carried less detritus, owing to a change in climatic or other conditions within their basins.

Erosion of the formation.—When deposition ceased, the present systems of drainage established themselves on the new deposits. Subsequent erosion has destroyed the flatness of the depositional surface by developing valleys of varying sizes below it. In places considerable undissected areas of the formation remain, and in such places the surface is nearly flat, as in the vicinity of Prospect Plains, northeast and west of Hightstown, north of Hartford, and northeast of Moorestown. These areas probably represent, approximately, the original surface of the formation. But in many places erosion has gone so far that the surface has been much dissected, and the topography advanced to maturity, and, locally, to old age. Many of the valleys have been cut through the formation into underlying beds, and in not a few cases the valleys in these underlying beds are wide.

Even in the Raritan Bay-Trenton-Salem valley, where the formation was best developed, it is restricted largely to the divides between the streams. Generally speaking, its areas are broad where the divides are broad, as between South River and Crosswicks Creek, and narrow where the divides are narrow. The remnants of the formation are so disposed as to show that it was once continuous between the areas where it now occurs, and that its dissected condition is the result of stream erosion.

Southwest of Crosswicks Creek, the broad valley plain on which the formation was best developed is crossed by numerous tributaries to the Delaware, whose courses are roughly from southeast to northwest. These streams have not only cut through the Pensauken, but they have removed much of it, and the areas remaining stand in somewhat definite relations to the streams which flow directly to the Delaware, being elongate on the divides between them. But in many cases another factor influences their position. Many of the remnants of the formation here have a pronounced northeast-southwest linear arrangement, in disregard of the courses of the streams. This arrangement is determined by the underlying formations, which have influenced,

and locally controlled, the drainage. This has gone so far that the divides, and with them some of the elongate areas of the Pensauken, correspond, in many cases, with the outcrops of the certain Cretaceous formations, and the outcrops are at right angles to the courses of the principal tributary streams.

In other places, as about Mount Holly, the Pensauken has been wholly removed from large areas. The underlying Cretaceous beds here were easily eroded, and the Pensauken formation has been more completely carried away from the upper parts of the basins of the streams than from the lower parts, where the underlying Cretaceous was less easily eroded, and where the valleys was therefore less readily widened.

Since the beginning of the interval of erosion which followed the deposition of the Pensauken formation, erosion has been the chief process affecting the topography of the region where this formation occurs. The only other change of importance has been the partial filling of some of the valleys, leaving them somewhat less deep than formerly.

STRATIGRAPHIC RELATIONS.

The base of the Pensauken.—As a rule, the elevation of the base of any given area of the Pensauken formation is nearly the same on all sides, especially if the area is small. Furthermore, the elevation of the bases of various areas which are near one another is, in most cases, nearly the same. This is the basis for the conclusion that the surface on which the Pensauken was deposited was essentially flat, though like all plains of subaërial erosion, it was not without some relief. To this general rule of planeness there were some distinct exceptions, as will be seen.

While the plain on which the Pensauken was deposited was being developed, Delaware River had a course similar to that which it now follows, and a large part of the valley plain below Trenton was developed by its tributaries. As a result, the plain declined slightly towards the Delaware, that is from the east-southeast to the west-northwest. Between Trenton and Raritan Bay, a large part of the corresponding plain was probably de-

veloped by tributary streams which flowed northwestward to the trunk stream which then flowed through the Raritan Bay-Trenton valley. This part of the plain of erosion, therefore, sloped gently from the southeast to the northwest toward the axis of the main valley. At the southeast the broad plain of degradation was limited by a low scarp, the slope of which was much greater than the slope of the plain to the main stream.

Aside from these low slopes which the plain possessed as a result of its mode of development, its surface departed from flatness in two ways: (1) There were some minor elevations above the general level, unreduced by erosion; and (2) there were valleys excavated below the level of the plain. The elevations were, in but few cases, more than 20 to 40 feet high; but there were occasional more considerable hills, such as Mount Holly, Mount Laurel, Arneys Mount, Disbrows Hill, and the Browntown hills, the highest of which were more than 100 feet above the plain on which they stood, before the deposition of the Pensauken formation. The low mounds on the peneplain were, in many places, buried by the Pensauken gravels and sands, but the higher hills were not buried. Such hills as rose 40 feet or more above the higher parts of the plain remained as hills after the deposition of the Pensauken formation. Good examples of low hills which were buried are found between Woodbury and Crosswicks, along the outcrop of one of the more resistant beds of the Cretaceous system. Their crests are now at an elevation of about 100 feet, and the Pensauken which once overlay them was thin.

The existence of valleys below the level of the Pensauken plain is revealed by later erosion, which shows the base of the Pensauken descending locally 40 or even 60 feet below its usual level. The complete cross-sections of the valleys below the Pensauken are not seen; but from the positions and relations of the low remnants of the formation, it is inferred that the valleys in the plain were narrow. Conspicuous examples are found at Fish House on the Delaware, at Rancocas, and at Kingston, just south of the Rocky Hill gorge.

The present elevation of the pre-Pensauken plain of erosion, that is the plain on which the Pensauken was deposited, is greatest at the northeast and decreases to the southwest. Along the axis of the valley, the base of the formation has an elevation of about 100 feet between South Amboy and Philadelphia, about 60 feet in the vicinity of Swedesboro, and 30 to 40 feet in the vicinity of Salem. East and south of the axis of the valley, the pre-Pensauken plain is somewhat higher. In the lower Delaware region, there seems to have been a rude but broad terrace east of the main valley plain, 30 to 50 feet above it. The Pensauken aggraded the lower plain to the level of this terrace, and spread out upon it in places at least. Locally, the base of the formation is considerably lower than would be indicated by the figures given above. In these places it appears to have filled narrow gorges below the level of the broad valley.

The altitude of the Pensauken surface.—The surfaces of remnants of the Pensauken formation are not, in all cases, to be taken as representing its original surface. In the vicinity of Salem and Alloway, the surfaces of Pensauken remnants have an altitude of 65 to 90 feet; about Auburn, 80 to 90 feet; at Swedesboro, 80 to 100 feet; at Haddonfield and Philadelphia, about 120 feet; at Rancocas, 90 feet; at Deacons Station, 110 feet; at Bordentown, 120 feet; at Trenton and Kingston, 120 to 130 feet; at Griggstown, 150 feet; at Allentown, 150 feet; southeast of Hightstown, at Englishtown, Hazlet, and South Amboy, 170 to 180 feet; and at Metuchen, about 130 feet. These heights vary much, but only the surfaces of the larger areas can be presumed to represent approximately the original surface of deposition. At the time of its deposition, the surface of the formation probably was lower than now.

If the elevations of the larger remnants mentioned above be taken as representing remnants of the original surface of deposition, and if the eroded beds of the formation were restored, the Pensauken surface would decline gradually to the southwest from an area about Hightstown and Englishtown, and from the same locality there would be a very slight decline to the northeast. Aside from these gentle slopes, minor slopes in various

directions can be made out. Thus there is a slope of 40 feet from South Amboy to Metuchen, of nearly as much from Englishtown to Griggstown, of 50 feet from Perrineville to Kingston, of 30 feet from Allentown to Trenton, and of 10 feet from Philadelphia to Haddonfield. These localities, taken two by two, are approximately at right angles to the axis of the valley. If these slopes could be assumed to represent the original surface of deposition, they would suggest either (1) that the main deposits were made from the southeast above Philadelphia, and from the west below that city, an inference not borne out by the constitution of the formation; or (2) that the original surface of the formation has been warped a little since its development, being tilted a little to the northwest at the north, and to the southeast at the south. Along the northwest margin of the plain at Metuchen, Trenton, and Philadelphia, the upper surface of the Pensauken has a nearly constant level. If the formation has been warped, therefore, it would seem that its northwest margin has remained more nearly fixed, or has moved as a unit, while the main body of the formation of the southeast has suffered more deformation.

At Raven Rock, 20 miles above Trenton, a bench at 200 feet, 140 above the river, is covered by what is probably Pensauken gravel, though good exposures have not been seen. The materials of the gravel are largely clastic (sandstone, quartzite, etc.), but bits of crystalline material occur. The gravel occurs down to Wilburtha, at progressively lower levels, but in meager remnants only. There is, however, enough to show its former presence.

The underlying formations.—The Pensauken sands and gravels rest on various formations of older rock. In the vicinity of Trenton, and thence to Princeton Junction, it rests on schists in some places, and about Philadelphia, it rests on similar beds over considerable areas. Here the upper formation thickens as the surface of the schist declines eastward. It most places the surface of the schist below the Pensauken is disintegrated to depths of 6 to 10 feet. Locally the disintegrated schist is so like the material of the Pensauken as to make their differentiation

difficult when exposures are poor, and it seems probable that much of the material of the younger formation was derived from the older.

Northeast of Trenton the northern part of the larger areas of the Pensauken formation lap up on shales of the Newark series. The relations are shown by Figs. 33–35. Far north of the Raritan Bay-Trenton valley there are remnants of the Pensauken formation on the Newark beds, but they are scattered and small. At Kingston the Pensauken occurs in a valley cut in the shale before the Pensauken epoch.

The larger part of the Pensauken lies on Cretaceous formations. It has been more completely removed from the Raritan than from the younger members of the system, apparently because the Raritan was more easily eroded than the others. Southwest of Trenton, remnants of the Pensauken overlie the Raritan between Rancocas and Coopers creeks; but elsewhere the outcrops of the Raritan formations have lost the Pensauken beds which overlay them. To the northeast, South River has removed the Pensauken from a large area, and this stream appears to have adjusted its course to the Raritan formation after it had cut through the Pensauken. Between Jamesburg and Trenton, more of the Pensauken remains on the Raritan formation. This is because the Millstone, which drains much of this region, crosses the Rock Hill ridge, the hard rock of which prevents the river from lowering its basin south of the ridge, as rapidly as South River lowered its basin.

The Merchantville to Wenonah formations, which constitute the Matawan group and overlie the Raritan-Magothy beds, were less completely planed down before the deposition of the Pensauken formation, and much less of that formation was deposited over their outcrops. Parts, indeed, were too high to be covered by the younger formation.

The outcrops of the Cretaceous beds above the Matawan group were still less generally covered by the Pensauken, because they were somewhat higher than the outcrops of the underlying formations; but in the basin of the Rancocas Creek, the surface of these beds was lower than elsewhere, and was more gen-

erally covered by the Pensauken. The character of the formation deposited upon the marls was somewhat different from that deposited upon the lower formations, nearer the axis of the valley.

In the southern part of the State, in the vicinity of Alloway, an area covered by the Kirkwood had been so reduced by erosion that it received the deposits of the Pensauken formation; but elsewhere the northwest edge of the Miocene was above the level of Pensauken aggradation.

Except on the southeastern slope of the Coastal Plain, the Pensauken does not lie on formations younger than the Kirkwood. The relations of the Pensauken on this slope will be considered later.

Relations to the youngest glacial drift.—At many places between Metuchen on the west and Perth Amboy on the east, the drift of the last glacial epoch overlies the Pensauken formation. The relations of the two show that the Pensauken was present in remnants only when this drift was deposited. Valley trains of gravel and sand borne out by rivers from the last ice sheet were deposited in the Delaware Valley after much of the Pensauken had been removed. Gravels of late glacial age (the Trenton gravels) overlie the Pensauken at Trenton. This relation has been seen repeatedly in temporary excavations, especially along the Pennsylvania Railroad near Clinton Street station, and at some points farther down the valley. Late glacial gravels occur also in the valleys of Bound Brook and the Millstone. The glacial gravel is distinct from the Pensauken in constitution; but where the rivers which carried the former flowed over the latter, the two types of gravel were more or less mingled in the deposits of the later epoch.

The two formations are distinct topographically in most places, but in the valley of the lower Delaware, the base of the Pensauken declines to the level of the sediments brought down the river in the last glacial epoch. Where this is the case, the two formations are not distinct topographically, especially where only the basal part of the Pensauken remains.

Relations to the early glacial drift.—In the vicinity of Metuchen, and between that place and New Brunswick on the one hand and Raritan on the other, there are occasional patches of Pensauken which are somewhat till-like in appearance, and in at least one place near Metuchen, glaciated bowlders have been found in it. The relations, however, do not preclude the hypothesis that the Pensauken proper antedated the surface parts which locally contain glaciated stones. In other words, it is not demonstrated that the glaciated materials associated with the Pensauken, are really parts of it. If the glaciated bowlders here are really in the Pensauken, they indicate that ice pushed down to the lower Raritan before the close of the Pensauken epoch. In some places, as at Raritan, material which has somewhat the appearance of old glacial drift overlies typical Pensauken gravel and sand. From Raritan it is but a few miles north to the border of well-defined glacial drift of an early glacial age.[1] In this region, it is not clear that the Pensauken and the old drift are closely associated in time. From all that can now be seen, the former might be older than the older glacial drift of the region. Other considerations, however, to be adduced later, suggest their close connection in time.

CONSTITUTION.

Physical characteristics.—The Pensauken formation is composed chiefly of coarse sand, with a subordinate amount of gravel, and a slight admixture of material of a clayey nature. Exceptionally, as at Fish House, the formation contains clay in considerable beds, and bowlders, even up to 4 to 6 feet in diameter, occur at its base in some places. The formation nowhere consists entirely of bowlders, of cobbles, of gravel, or of sand. Almost everywhere it is made up of a mixture of these materials, especially sand and gravel, in varying proportions. In some places it consists of sand with occasional pebbles, in others of compact gravel with interstitial sand only. The gravelly parts vary from fine gravel with an occasional cobble,

[1] Glacial Geology, Vol. V, p. 753.

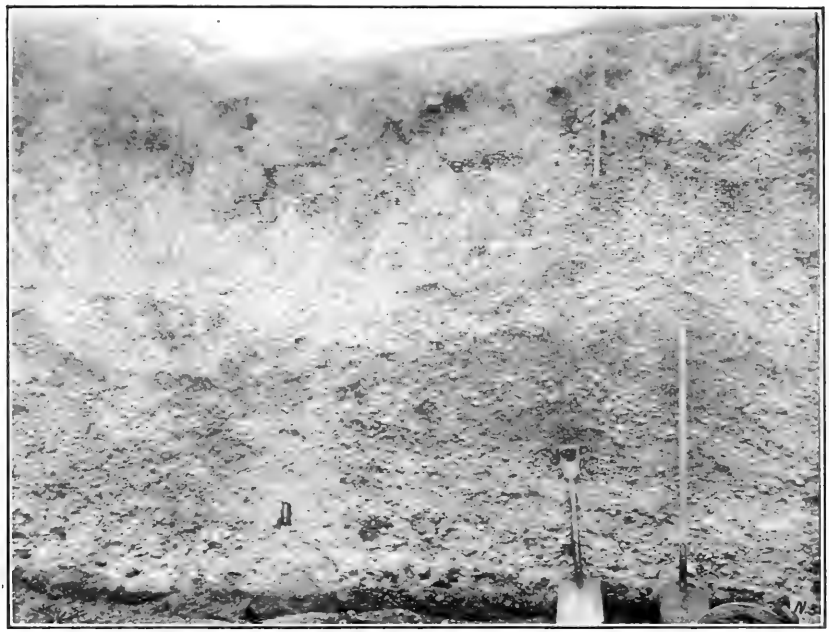


Fig. 31.

Pensauken formation, G. A. Bowne's pit, 1 mile east of Bustleton Church. Note the promiscuous distribution of the pebbles.

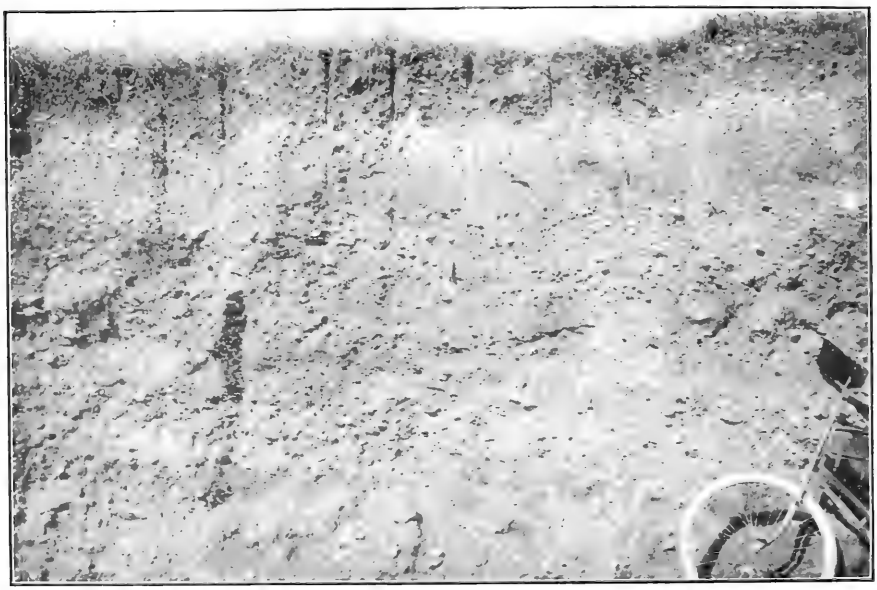


Fig. 36.

Pensauken formation, Cole's pit, Colestown, Camden County. The material is largely of local origin, most of the pebbles being derived from the southeast. There is, however, a little Triassic shale and crystalline material.

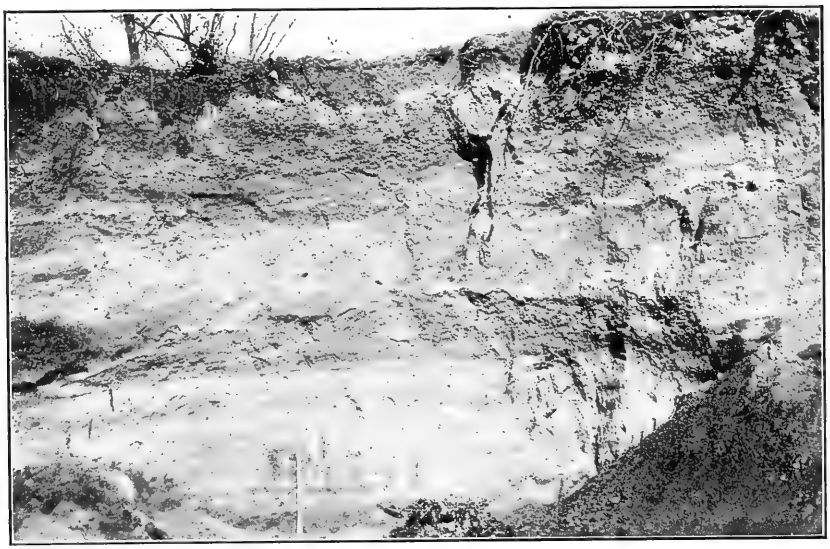


Fig. 37.

Pensauken formation, Hylton's pit, Palmyra, Burlington County. Only the upper part of the formation is shown.

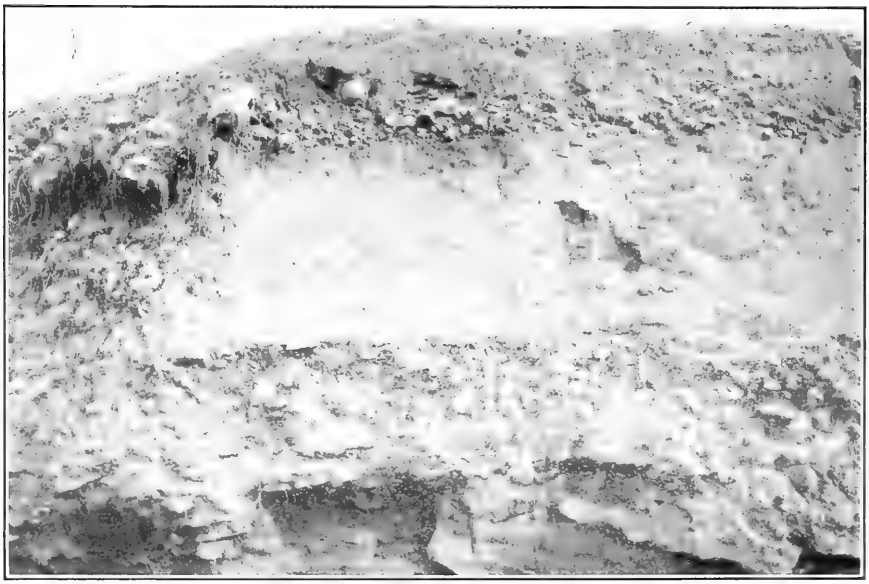


Fig. 38.

Pensauken formation, Hylton's pit, Palmyra, Burlington County. The basal portion of the formation shows two cobble beds, more or less cemented, separated by a foot and a half of arkose sand.

to cobble beds with fine gravel and sand in the interstices, as at Kingston.

The gravel includes quartz, quartzite, sandstone, chert, shale, crystalline rock such as granite, gneiss, schist, gabbro, diabase, etc., and ironstone. No piece of limestone has even been seen in it. Among the pebbles and bowlders, the amount of crystalline material present ranges from 0 to 10 per cent., shale from 0 to 80, sandstone from 0 to 20, chert from 2 to 30, ironstone from 0 to 70. The gravel may be scattered promiscuously through the sand (Fig. 31), or it may be in beds or lenses (Fig. 36). It is, on the whole, more abundant at the bottom, and in the upper part of the formation, than at intermediate horizons (Figs. 37 and 38), but bodies of gravel in the middle portion are by no means unknown (Fig. 39).

The sand is quartzose, arkose, and in many places glauconitic. Glauconite may be in any proportion up to 90 per cent., though more than 10 per cent. is rare. Loam and clay are, as a rule, present in small quantity only.

Where arkose, the material is usually compact and coherent, and is extensively used for road material. The abundance of soft chert, shale, decayed bits of igneous and metamorphic rock, together with decayed feldspar and loam, cause it to pack well in road beds. In not a few places the material of the formation is partially cemented (Fig. 40). Locally, faulting on a small scale is shown, the gravel and sand being compact enough to behave like solid rock during movement (Fig. 41, p. 104).

Sources of material.—Among the stony materials of the Pensauken the following can be identified:

1) *Schist* like that which occurs at Trenton and Philadelphia, is common in the Pensauken below Trenton, but cannot, as a rule, be referred to any particular part of the schist area.

2) *Black shale,* with abundant impressions of plants, like that quarried at Milford, 30 miles above Trenton. Pieces of rock of this sort have been seen most frequently in the Pensauken formation between Burlington and Mount Holly, and about Deacons Station. The shale is certainly from the Newark series, though it may have come from some point other than

Milford. Deacons Station is about in line with Neshaning Creek (Pa.), which crosses Triassic beds.

3) *Stockton sandstone* like that quarried at Stockton, is found at many points. Since this sandstone is somewhat widespread, the material in the Pensauken need not have come from the immediate banks of the Delaware. Conglomerate from the Stockton formation is found with the sandstone.

4) *Red shale and sandstone* from the Brunswick division of the Newark series, and perhaps from other formations. It is not certain that all the red sandstone is from the Newark series. In the Bridgeton formation, a piece of red rock was found, very like the Newark sandstone petrographically, which contained a Pennsylvanian (late Carboniferous) fossil.

5) Pieces of *igneous rock* from the Newark series.

6) At the northeast, pieces of *conglomerate* which are probably from the Green Pond Mountain formation.

7) *Granite pebbles* and bits of *gabbro,* the sources of which are not known.

8) *Ironstone fragments,* derived from the Coastal Plain formations (Cretaceous and younger) older than the Pensauken.

9) *Quartz pebbles,* some of which show a peculiar columnar structure as they weather. Vein quartz from which they might have been made is found in the Martinsburg (Hudson River) formation of the northwestern part of the State. As constituents of the Pensauken formation, these quartz pebbles probably came from older formations of the Coastal Plain.

10) *Chert pebbles,* derived, like the last, from the Tertiary and early Quarternary formations of southern New Jersey.

11) *Glauconitic sand* from the Cretaceous is prominent, as already noted, along the southeastern border of the main Pensauken belt.

Subdivisions.—Between South Amboy and Woodbury a threefold subdivision of the Pensauken is recognizable in some places, but not in all. (1) The basal member is a thin bed of gravel, in many places coarse, generally carrying some crystalline rock material and some shale. Bowlders are not altogether wanting—are, indeed, much more common than in any other part of the

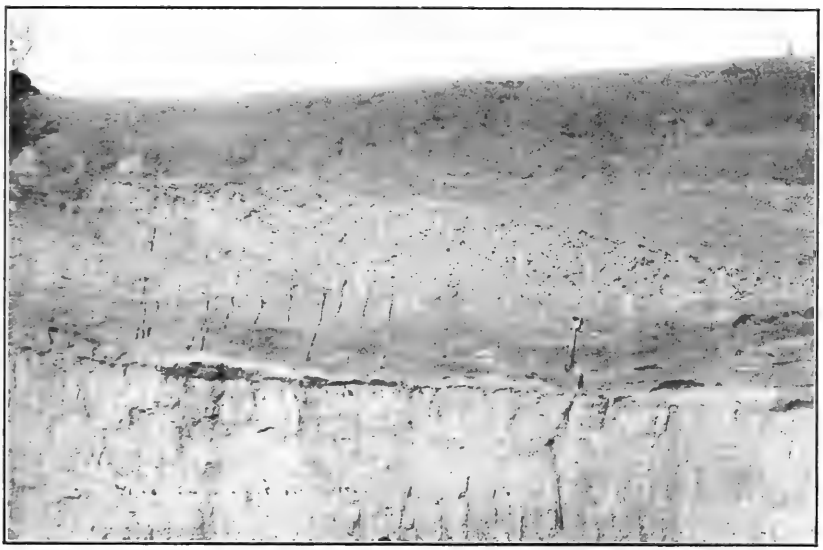


Fig. 39.

Pensauken formation on white Raritan (Cretaceous) clay. Hylton's pit, Palmyra, Burlington County. Note the cross-bedded structure in the Pensauken.

Fig. 40.

Pensauken formation at Westville, Gloucester County, cemented by iron oxide. Excellent road material.

formation. This member is rarely more than a foot or two thick. (2) The middle member is predominantly of sand. More commonly than otherwise, the sand is arkose and well stratified. It contains little gravel, though pebbles occur singly and in thin beds which appear as bands in sections. Bowlders and cobbles are virtually absent. In thickness, it varies greatly. Where the formation is thickest, this member makes up the larger part of the whole. (3) The uppermost member is gravelly, the gravel being rather fine, with some admixture of loam, and without distinct stratification. This member is thin, in most cases less than 10 feet, and in many places not more than 4 or 5 feet.

This three-fold subdivision can be looked upon as having a general application only. At many points it is not apparent. In many places material corresponding in physical constitution to but two of the three members is present, and the one which appears to be wanting may be any one of the three. Nevertheless the following generalizations seem to be warranted: (1) that during the earlier part of the Pensauken deposition more coarse material was contributed to the deposit than at any other time, and that of this coarse material a larger percentage was of crystalline rock or shale, than at any later stage of the epoch; (2) that during the middle and probably the greater portion of the epoch, sand, mostly arkose, was the chief constituent of the deposit; and (3) that during the later portion of the epoch, gravel was again more abundant, but gravel in which crystalline rock and shale were almost wanting. The region from Raritan to Raritan Bay was an exception to the last statement above, for here the last phase of the Pensauken appears to have been near the edge of an ice sheet, and in it shale and crystalline material are abundant.

The middle member is the only one which shows distinct stratification persistently. Its individual beds are in places thin and horizontal, but sharp cross-bedding is almost equally common. Where gravel is associated with the sand, the pebbles are in many cases in thin beds, making lines of pebbles as seen in section.

Geographic variations.—The Pensauken formation has its best and most distinctive development in the Raritan Bay-Trenton-Salem depression, a belt 10 to 20 miles wide and about 90 miles long. Throughout this valley, wherever sufficient remnants of the formation are present to afford a basis for generalization, it is found that the constitution of the formation changes from its northwest border toward the southeast. This change affects both the size and the kinds of the constituents. The sorts of material which are coarse along the northwestern margin, become finer to the southeast, and the decrease in coarseness from the northwest may be said to continue to the line A-B of Fig. 42. Considerable bowlders (2 to 4 feet in diameter) are not rare, and in places they are common near the northwest border of the belt. All of them are from formations which outcrop to the north. But as the line A-B is approached from the northwest, large bowlders become rare, and reach a foot in diameter in exceptional cases only.

A change in the lithologic character of the material accompanies the change in size noted above. While pieces of granitic and other igneous rocks are common along the northwest border of the formation, they decrease toward the line A-B, Fig. 42. Shale and sandstone derived from the Newark series have the same distribution; and so have pieces of sandstone and quartzite from the Paleozoic formations north and northwest of the Newark series.

Southeast of the line A-B, bowlders of northwesterly origin are essentially absent almost everywhere; but bowlders derived from formations of southern New Jersey are present. Fragments of ironstone (sand cemented by iron oxide) derived from the Cretaceous and younger formations are rare along the northwest border of the belt, but abundant to the southeast (especially southeast of the line A-B, Fig. 42), where, locally, they constitute as much as 70 per cent. of the gravel. Pebbles of quartz, too, are less preponderant to the northwest than to the southeast. These pebbles in this formation were derived in large numbers from the Bridgeton and other beds which lay to the southeast. They and the ironstone make up most of the stony

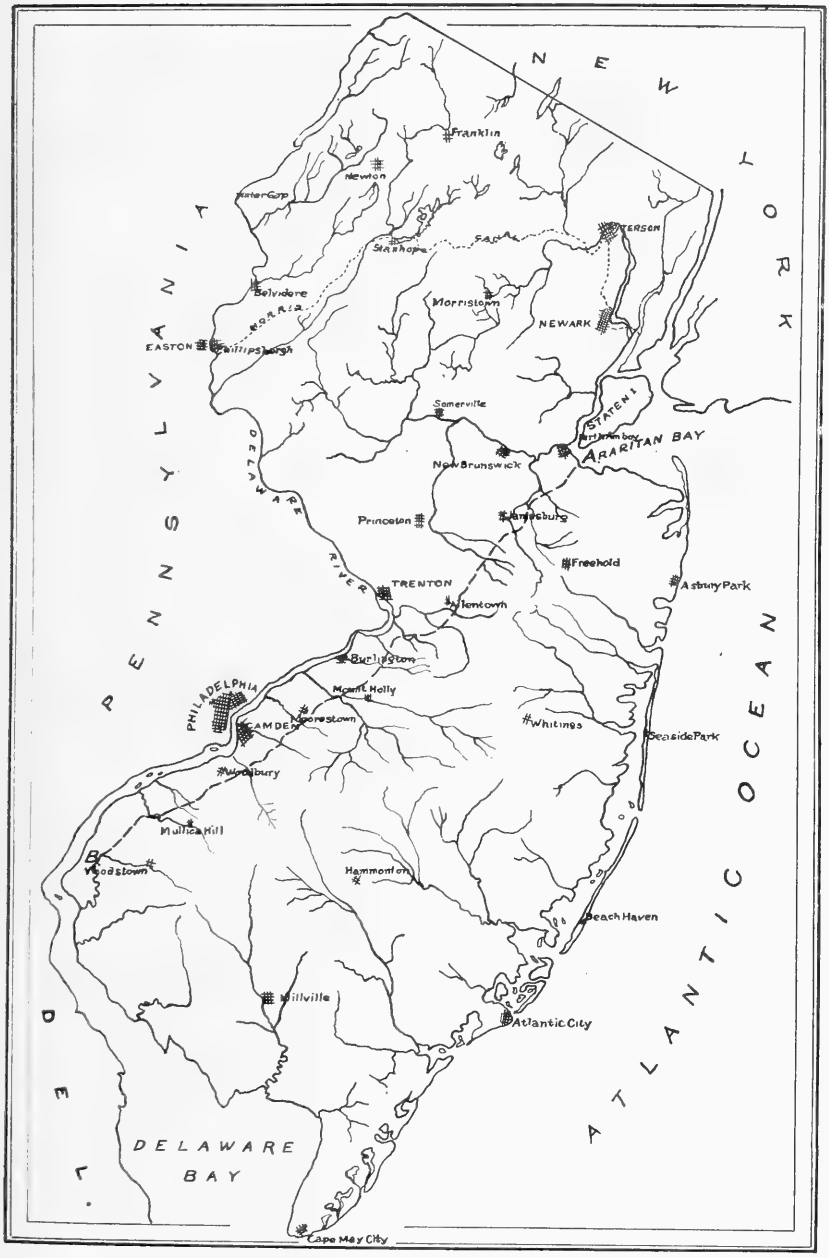


Fig. 42.

Outline map of New Jersey showing line of demarcation (A—B) between the arkose Pensauken on the northwest and the locally derived Pensauken on the southeast.

material southeast of the line A-B, Fig. 42, though some chert is present in most places.

Among the finer sandy constituents of the formation, glauconite is absent or rare at most places along the northwest border of the formation. Along the center of the belt it is present in small quantity in many places, and southeast of the line A-B there are considerable beds of Pensauken sand in which glauconite grains make up 10 per cent. or more of the whole.

The changes in the constitution of the formation from northwest to southeast outlined above are less distinct below Woodbury than farther north. This is perhaps because the remnants of the formation remaining at the south are less extensive than those to the north, and form a less adequate basis for comparison.

These changes in the coarseness and in the petrographic constitution of the formation are intelligible if the formation was deposited primarily by land waters flowing to the main valley, from the northwest on the one side, and from the southeast on the other. The waters from the former direction brought in materials from the north and west, the coarse being deposited first. The drainage from the southeast, flowing over different formations, brought in different materials, and their coarser parts were left first, near the southeast margin of the broad area of aggradation. Toward the center of the belt the materials from opposite directions are much mingled.

It seems probable that a similar distribution of materials would exist if the broad valley under consideration were submerged during the deposition of the Pensauken formations. If it were converted into a sound, rivers would have contributed sediment to its borders from either side, and the waves of either shore would have acquired materials from the formations found there, the coarser being carried out lesser distances from the shores. Even in this case much of the material must have been contributed by rivers, for the shores of the sound would nowhere have touched granitic rocks, or Paleozoic sandstone and quartzite. They would have touched the red shale and trap rock of the Newark series; but it is not clear how materials from

these formations could have been carried across the sound to the opposite side, if waves and currents only were the agents of transportation.

The line A-B of Fig. 42, referred to repeatedly in the preceding paragraphs, is not to be understood to be an absolute line which materials from opposite directions did not cross. It is rather the line along which materials of northwesterly origin, abundant at the northwestern margin of the belt, become so unimportant quantitatively as to be negligible. If a line were to be drawn representing the northwestern limit of southeastern material plentiful enough to be recognized readily, it would be essentially parallel to A-B, but a little northwest of it.

Differences in sand go with differences in the coarser materials. Thus where the glauconite is wanting, the sand is, as a rule, more or less arkose. Along the southeastern part of the belt (southeast of A-B, Fig. 42), where glauconite is common, the sand is rarely arkose. Northeast of Crosswicks Creek, there is a rise of 20–40 feet in the base of the Pensauken, going southeast, about where its arkose character disappears.

Local variations in constitution.—There are some areas where bowlders are much more abundant than in others, irrespective of distance from the northwest border of the formation. Thus in the area southeast of Trenton (near Bordentown), bowlders are relatively abundant, and of larger size than in most other places. This area, it will be noted, is below the point where the Delaware leaves the harder formations north of the Coastal Plain, and takes its course across the Cretaceous system. The bowlders here were probably brought down by the Delaware, and left where its gradient became low on the weaker formations. Another area of abundant bowlders is south of New Brunswick, an area which stands in a somewhat similar relation to the Hudson.

At Kingston, just south of the Rocky Hill gorge, is the coarsest bed of gravel known in the Pensauken. The material is entirely of northern origin, and was apparently left by a stream which, at the time of deposition, flowed south to this point from the Highlands. The gravel at Kingston is but a

remnant of a deposit which was, at the outset, much more extensive.

In the vicinity of Philadelphia, the bottom of the formation runs down below its normal level in a relatively narrow pre-Pensauken valley in the bottom of the broad Delaware Valley. When deposition began, this narrow valley was filled with such material as the drainage then afforded. Later, after its bottom had been filled, deposition took place at higher levels.

The deposits of the lower level, especially below 40 feet, are somewhat unlike those of higher levels, especially above 70 feet. Between these levels there is a mixture of the material characteristic of the lower and the higher horizons. The Pensauken material at the low levels is composed of quartzitic material largely, with some gneiss, schist, and shale, but with little granitic gravel. Its elements are not well rounded, and have been worn but little. The gravel appears to have been brought to its present position by the Schuylkill, and becomes finer with increasing distance from the debouchure of that stream. Above the 70-foot level, the Pensauken is commonly arkose, as generally in the area where it is normally developed. This arkose material was probably contributed in part by the Delaware after that river began to bring its load of gravel and sand down to this latitude; but much of it came from the schists of the Trenton-Philadelphia region. Pensauken gravel and sand likewise fill some rather deep side valleys in this latitude, one near the present course of Crosswicks Creek, and others farther south. In the side valleys, the difference between the material of the upper and lower levels is not so pronounced.

Bearing of constitution on origin.—The persistence of the arkose sand and its uniformity over great areas, has a bearing on the origin of the Pensauken. At first thought, it might seem to favor the hypothesis of submergence, as a deposit in a sound might be more uniform than deposits made by a series of rivers. This argument is, however, not very convincing, since the materials for the deposit, even in a sound, would have to be contributed by rivers, to a large extent.

There are local variations in composition corresponding, in a measure, with what might be expected along shores. Thus along

the northwestern border there is much shale in the Pensauken, at least in spots. This is true, for instance, northeast of Trenton. Southeast of Trenton, where the underlying formation is schist, much material from this formation appears in the gravel. On the other hand, the correspondence between the composition of the younger formation and the character of the base on which it rests, or of the older rocks against which it abuts, is not so close as the shore hypothesis seems to demand. Shaly material is found in spots, at least, far from the outcrops of the shale, and on the opposite side of the hypothetical sound.

The arkose character of the sand is well developed from Trenton to Wilmington near the Delaware, about Hamilton Square, Newtown, Hightstown, South Amboy, Old Bridge, and Woodbridge. From both the northeast and southwest, the arkose character becomes less conspicuous towards Jamesburg, where much of the formation seems to have come from the south. This suggests that the Delaware and the Hudson were the great contributors of the arkose sands, and that at Jamesburg, about equally distant from the two sources, it is least prominent.

Theoretically the Raritan was equally well situated for bringing in arkose Pensauken gravel, but in that part of its former basin which is low enough to have received deposits, remnants of the Pensauken are small.

There is nothing in its constitution to negative the hypothesis of the whole formation being river work, nor is there anything, as now understood, to prove it. The widespread uniformity of the second number (p. 81) might be said to argue submergence. The upper member, on the other hand, is more like flood plain deposits, or subaërial wash. The basal member, also, is not unlike a river deposit, though it is difficult to understand how such coarse material could have been carried by rivers so far with so little rounding. The help of floating ice seems to afford the only escape from the difficulty.

The absence of fossils in all places where the formation is normally developed, is negative evidence. The condition of the formation in most places is such that fossils could not have been preserved, even had they been abundant at the outset. At Fish

House, but little above sea level, fresh-water shells are found in clay which is probably to be correlated with the Pensauken. On the whole, the belief is entertained tentatively, that rivers were the agents chiefly concerned in the depositions of the formations, and that such part (if any) of it as is marine is very subordinate.

THICKNESS.

The formation was, on the whole, thickest along the axis of the Amboy-Bordentown-Salem belt, and thinned both to the northwest and southeast. The greater thickness near the axis of the belt seems to be because the bottom of the valley was lowest there, when deposition began.

It is probable that the original maximum thickness of the formation in the vicinity of Philadelphia was not less than 120 feet. This is the elevation of its surface in Philadelphia, and at Haddonfield on the east side of the river. In the vicinity of the city hall in Philadelphia excavations down virtually to sea level have been seen, showing Pensauken gravel down to that level.

In the vicinity of South Amboy, the surface of the Pensauken reaches an altitude of 170 feet. The level of its base is about 90 to 100, but in two spots in that vicinity its base is known to go down to within 20 feet of tide level. If the Pensauken material at these low levels is not the result of slumping, it indicates great maximum depth of the formation here.

The average thickness of the formation, *as it now exists,* is much less than that suggested by the figures given above. In the vicinity of Philadelphia, it is commonly not more than 10 to 20 feet outside the deep valleys. About Bordentown it has a depth of 20 to 40 feet; about Jamesburg, 40 to 60 feet; and at South Amboy, as much as 70. Its average original thickness was doubtless more than the smallest of these figures, and less than the largest.

AREAS SOUTHEAST OF THE MAIN BELT.

Southeast of the main belt of the formation, there are many areas of gravel and sand, some large and many small, which are, perhaps, to be correlated with the Pensauken formation. The areas in question are partly to the north and west of the main divide of southern New Jersey, and partly to the southeast, on the Atlantic slope. In general, these parts of the Pensauken formation, if such they are, lie on divides and hills, though not on the highest divides and hills along the crest of the watershed. Their altitude is greatest as this divide is approached, whether from the north and west, or from the south and east. Near this divide, their altitude is somewhat greater than that of the Pensauken formation in the Raritan Bay-Trenton belt. From this divide the altitude of these areas declines with the streams in both directions, so that the altitudes have a wide range, from 200 feet or so at a maximum, down to 60 feet or less at the southeast, far from the main divide of the southern part of the State. Many of the patches of gravel in this area are so arranged as to suggest that the material was deposited by streams flowing parallel to those of the present time. Some of the patches, on the other hand, show no such association with the courses of existing streams.

In essentially all cases—perhaps in all—the materials of these areas came from underlying and adjacent formations. At the northwest and west, the Cretaceous formations contributed much. This is true in most places north and west of the main divide. On the Atlantic slope, on the other hand, the streams, as a rule, had no access to Cretaceous formations, and the Tertiary and earlier Quaternary formations were the immediate sources of the material regarded as probably Pensauken. The sand is not arkose, and the gravel consists of quartz, chert, etc., from the Bridgeton and Beacon Hill formations, and of ironstone, derived from the cemented parts of the older formations of the region. Where the Cretaceous formation contributed, glauconite is present commonly. Sand definitely recognized as from the Miocene, is found in many places. So also is sand from the Cohansey

(Pliocene?) sand beds. In addition to these finer materials, there are some large bowlders of quartzite from the Kirkwood (Miocene), for though most of the Kirkwood sand is not cemented, it appears to have been cemented to quartzite in a few places, and these portions have given rise to bowlders. The "Lime Sand" of the Cretaceous also has given rise to bowlders in some places.

This non-arkose phase of the Pensauken is thin for the most part, and its remnants scattered. It is doubtful if it ever covered the whole of the area within which it is found, and much of that which once existed has been removed. If these deposits be fluvial, they were made along the water courses of the time, and large areas were perhaps never covered by them. If this view is correct, some of the old stream courses have since become divides. Since glacial waters did not affect the streams concerned in the deposition of this phase of the formation, the deposits were much less considerable than in the main Raritan Bay-Trenton valley. Furthermore, the streams involved were all small, as compared with those which contributed to the main area of the Pensauken formation, and they did not come from areas of such great altitude.

Differentiation of the formation, especially on the southeast slope, is difficult, for deposition by streams has taken place in later time, and these later deposits (Cape May formation) rise upstream, and in many places reach levels which make them inseparable, topographically, from the deposits of the Pensauken epoch. In constitution, too, the gravels of the two ages are essentially the same. The most persistent differences are (1) the apparent greater age of the Pensauken, as contrasted with the Cape May. This is shown by more cementation, more incrusting of grains and pebbles with iron oxide, more oxidation of glauconitic grains, more decay of chert, etc.; and (2) topographic position, for much of the Pensauken occupies divides, while most of the Cape May formation is in the form of terraces, or on lowlands near the shore.

Local Details.

THE LOWER DELAWARE VALLEY.

The pre-Pensauken surface.—In pre-Pensauken time, the Delaware flowed about where it is now, and received tributaries, somewhat as now, from the east. Along the lower course of the main stream there were two bordering plains or broad terraces. The lower plain or terrace, which will be called the *Swedesboro Plain,* lay nearer the Delaware, and was limited at the southeast by an interrupted scarp extending from Cinnaminson, Merchantville, Mt. Ephraim, Woodbury, Swedesboro, Auburn, through or near Halltown, to Mannington Creek. The higher plain or terrace to the southeast, the *Woodstown Plain,* was about 50 feet higher, 3 to 5 miles wide, and was in turn limited at the southeast by another scarp. These scarps were determined by the outcrops of certain resistant beds of Cretaceous. The principal pre-Pensauken tributaries corresponded in position, in a general way, with the present Alloway, Salem, Old Mans, Raccoon, Mantua, Timber and Coopers creeks. Below the lower terrace, the streams had rather narrow, shallow valleys.

During the Pensauken epoch, deposition was heaviest on the Swedesboro Plain, and on this plain, it was greatest near the Delaware. Deposition on this plain continued until it was built up nearly or quite to the level of the Woodstown Plain. The deposits on the lower plain contain, in most places, some arkose sand and gravel which appear to be the contribution of the Delaware and the Schuylkill rivers, while the contemporaneous deposits on the Woodstown Plain were chiefly of non-arkose material brought down from the east and southeast by the streams coming to the Delaware from that direction.

The existing remnants of the Pensauken are much more extensive on the Swedesboro Plain than on the Woodstown Plain above. It was more widespread and more continuous on the lower plain at the outset, and subsequent erosion has removed

it from a larger proportion of its original area on the higher plain, for here its development was largely in valleys, and the streams of later times have carried much of it away.

It is quite possible that some remnants and patches of gravel and sand interpreted as Pensauken, especially on the Woodstown Plain, really antedate the time of principal Pensauken deposition, being remnants of gravel accumulated on the surface during the pre-Pensauken interval of erosion. Minor deposits, as is well known, may be made on a surface where degradation is the dominant process.

Deposits south of Salem Creek.—South of Alloway, on the divide north of Deep Run, and again west of Deep Run, 1½ to 2 miles southwest of Alloway, are considerable areas of sand and gravel regarded as Pensauken. Smaller areas occur 1 and 2 miles east of Alloway, one on a low divide, and one on a hilltop. In this vicinity, there is little distinctive material in the Pensauken or in what is interpreted as Pensauken. The material is largely of loam with some sand, and a thin bed of gravel at the base. The coarser materials are of easterly origin. The remnants are so disposed as to suggest that a mantle was once widespread at an elevation of 60 feet or so in the vicinity of Alloway, and 90 feet or so 3 or 4 miles farther east. The material is classed as Pensauken chiefly on the basis of its topographic position. Its altitude and the isolation of the elevations which it caps, are harmonious with the corresponding features of the distinctive Pensauken farther north. The materials were probably deposited by tributary streams after the Delaware had begun the aggradation of its valley in the Pensauken epoch. Such a filling in the main valley would have necessitated deposition in the valleys of the tributaries.

East of Alloway the material mapped as Pensauken is mostly sand derived from the Cohansey formation, reworked and redeposited; but locally the Miocene clay of the region has contributed much to the formation.

In places, as northeast of Alloway, the materials interpreted as Pensauken are disposed in elongate patches, perhaps representing the former courses of streams. As a result of later erosion, these old stream courses, with their deposits of sand

and gravel, came to be ridges, while the more easily eroded materials on either hand was carried away. Up-stream, the old valley deposits become less and less distinctive, and merge into the valley deposits of more recent times. Here, as elsewhere, the site of deposition in the valleys moved up-stream, as the stream advanced in age. In the Pensauken epoch the streams tributary to the Delaware were shorter than now.

Two to three miles north of Alloway, near Riddleton, a section at an elevation of about 80 feet shows[1]

3) 1–3 feet of clay loam.
2) 4 " of stratified sand and clay.
1) 2 " of gravelly clay.
Miocene clay (at the base).

Similar sections are repeated many times in the vicinity. The pebbles are mostly quartz, chert, and sandstone, and their surfaces in many cases are coated with iron oxide, giving them a rusty appearance.

Another section seen about 3 miles northeast of Alloway showed

3) 3 feet of gravel, sand and loam, with cobbles, and even bowlders 1 foot in diameter.
2) 1 foot of conglomerate, cemented by iron oxide.
1) 2 feet of sand.
Miocene clay.

Similar sections occur at various points in the region between Alloway and Yorktown, at elevations of 60 to 90 feet, mostly on the low divides.

East of Welchville, in a hilltop at an elevation of 64 feet, the section of material regarded as Pensauken is as follows:

3) 2 feet of sandy loam.
2) 2 feet of sandy gravel.
1) 10 feet of sand, white, yellow, brown, with thin layers of black grains.

[1] In all sections following, the lowest member is at the bottom, and is numbered 1). The second member from the bottom is numbered 2), and so on.

"Bullshead" bowlders are scattered over the surface at some points between Mannington and Salem creeks, and in places they have been gathered into considerable piles. They are relics of the Miocene sand which once covered the region, and which was, in spots, cemented into quartzite. Occasional bowlders are 3 feet in diameter, as southeast of Halltown.

In the patches of Pensauken gravel about Big Mannington Hill, 4 miles north of Alloway, there are slabs of conglomerate, the conglomerate containing pebbles of quartz, chert and sandstone, cemented by iron oxide, and clearly derived from the Bridgeton or the Beacon Hill formation.

Between Salem and Raccoon creeks.—Between these creeks the Pensauken gravels and sands lie mostly between the levels of 50 and 80 feet at the west, but rise eastward to levels of 100 feet or so within 4 to 6 miles. The formation is in patches only, and the smaller patches are mostly on low swells near the streams, somewhat below the level of the divides.

A considerable bed of Pensauken occurs just north of Woodstown at an altitude of about 60 feet. The material consists of sand from the Kirkwood formation to the north and east, and gravel and sand from the Cohansey and Bridgeton beds to the east. The materials are so distinctive as to make identification of their sources easy. They might have been brought to their position by Salem Creek and its tributaries, or by streams following the general courses of the creeks named. A section here shows:

3) 2 feet of pebbly yellow loam (post-Pensauken), or a weathered product of 2.
2) 6 feet of compact red brown sand, gravel and loam.
1) 3 feet coarse sand, with grains slightly coated with clay, giving the whole a somewhat arkose appearance.

The relations of the Pensauken here to the Bridgeton are shown in Figs. 16 (p. 40) and 43 (p. 136).

Toward the creek the formation runs down to the Cape May level (to 50 feet, and possibly to 30), and where this is the case the two formations are distinguished by constitution only (Figs. 16, 43). In places the Cape May laps up over the Pensauken,

concealing its lower edge. The bottom of the pre-Pensauken valley here was as low as the present 40-foot level.

Between Woodstown and Auburn, there are a few patches of non-arkose gravel on divides and crests, doubtfully correlated with the Pensauken. The patches in question occur at altitudes ranging from 70 to 114 feet, and some of the gravels may be deposits left during the time of general degradation which followed the deposition of the Bridgeton formation, and preceded the deposition of the Pensauken.

Below Auburn, the Pensauken is somewhat arkose, a characteristic which persists to the northward and northeastward. Even the Bridgeton formation of higher levels did not furnish arkose material, shale, etc., to the Pensauken of the upper part of the valley of Old Mans Creek. If these materials were acquired by this stream in the Pensauken epoch, as seems probable, the soft shale and decayed crystalline rock were worn out during their transportation, and do not appear in the gravelly parts of the deposit. The arkose element at Auburn is the contribution of the Delaware. Auburn is about the place where the arkose, Delaware phase of the formation meets the non-arkose phase, lying farther from the main stream. The general relations of the formation in this latitude are shown in Fig. 43.

A mile and a half northwest of Auburn, there is at least 15 feet of arkose sand, with occasional pebbles of red shale. In this vicinity, too, a few bits of trap rock are found, and even an occasional bowlder. Trap rock has not been seen in the Bridgeton of this general region, and it is believed to have come down the Delaware during this epoch. Here, too, the Pensauken contains granite pebbles not seen in the Bridgeton in this vicinity, though bits of gneiss occur in that formation. To the west, the base of the Pensauken descends to 30 feet, or even lower, beneath the Cape May formation.

At Auburn the non-arkose phase of the formation runs up to the altitude of 100 feet more or less. It is an open question whether the arkose phase reached the same level, being degraded later.

There are numerous patches of Pensauken on the north side of Old Mans Creek, which appear to represent former stream accumulations of gravel and sand. It is probable that the streams have since, by monoclinal shifting and otherwise, abandoned their old channels filled with gravel and sand, and that these channels, by subsequent erosion, have become low ridges. The Pensauken remnants from Harrisonville west, therefore, may perhaps mark roughly the former course of Old Mans Creek, or its antecedent. The constitution of the Pensauken changes down stream. Each formation crossed by the stream contributed material to the deposit below its outcrop, and these materials are easily distinguished. This variation in constitution is, of course, good evidence of the fluviatile origin of the material.

The remnants of the formation differ in their topographic positions and relations. At Harrisonville the remnants are well down the slopes of the valley, at levels of 80 to 100 feet, and not distinctly separated from the Cape May formation. Near Auburn, they are on slopes mostly between 70 and 50 feet, and on a divide up to 100 feet, and are topographically distinct from the Cape May. Some of the patches on the north side of Old Mans Creek are continuous from elevations of 100 feet, down to 50 feet. If the lower part is not displaced, it shows a pre-Pensauken slope toward the axis of the present valley of 40 to 50 feet. At Auburn, on the south side of the creek, the relations are similar. If these beds were on slopes originally, the surface must have been built up in Pensauken time, to a level which is now 100 feet or so above sea level. As in many other places, it is not demonstrable that the Pensauken in the valley of Old Mans Creek above Auburn, is the exact equivalent of the arkose Pensauken west of Auburn; but their topographic relations seem to place their deposition at about the same time.

On the other hand, it cannot be too often reiterated that the deposition of sediment in valleys is a more or less continuous process. Even in a region like this, where epochs when deposition predominated, alternated with epochs when erosion predominated, there was some deposition in times of dominant erosion, and doubtless some erosion in times of dominant deposition. In the region, therefore, there are doubtless gravels

of various ages, some of which antedate, and some of which follow the main Pensauken deposits, and their definite separation is impracticable.

At Auburn the Pensauken gravel is cemented locally by iron oxide to conglomerate, the cemented beds being 4 or 5 feet thick. This may be seen in a gravel pit just east of the village, and again about a mile east of Auburn, on the south bank of Old Mans Creek, capping an isolated hill. Other examples of the cemented Pensauken are seen on the north side of the valley, 1 to 1½ miles northeast and east of Auburn. Farther up the valley cementation is less common. There is apparently some relation between the cementation and the nature of the base, cementation being more common where the Pensauken lies on the Cretaceous (Auburn to Harrisonville Station), than where it covers the Miocene (Harrisonville to Harrisonville Station).

Other patches of arkose Pensauken exist west of Swedesboro, at levels of 70 feet and less, declining to 40 at the west. Here the younger Cape May formation overlaps the low western edge of the arkose Pensauken, and the Pensauken descends beneath the Cape May, at Center Square. Its base therefore declines westward toward the Delaware.

Just south of Robbins Hill, the non-arkose phase of the Pensauken gravel occurs at 100 feet, and is very like the corresponding phase at Auburn at the same level. The arkose Pensauken here is distinctly lower. This relation, taken by itself, suggests a twofold division of the Pensauken, a younger, lower, arkose division, and an older, higher, non-arkose division; but evidence suggesting the unity of the two phases is at least equally good, even in this region, and is convincing (Knapp) in some others.

A characteristic section of the non-arkose Pensauken, a mile west of Harrisonville, is as follows:

5) 3 feet yellow loam and sand.
4) 8 feet gravelly yellow sand, gravelly gray sand, and clay loam, gray sand and clay in alternating thin beds.
3) 2 feet pale bluish white gritty clay.
2) 6 feet of compact gravel.
1) 8 feet of gray sand with about 5% of glauconite.
Cretaceous.

While an exceptionally thick section (27 feet), its composition is characteristic of the formation in the valleys of tributary streams.

Between Raccoon and Mantua creeks.—Very considerable beds of arkose Pensauken are found north and west of Swedesboro, between Rulons and Clarksboro, on the Swedesboro Plain. At the northwest, the base of the formation has an altitude of 20 to 50 feet, and at the southeast, 50 to 90 feet. In places there are 20 to 30 feet of arkose sand, with only occasional seams of pebbles, among which shale and bits of crystalline rock occur. If the very base of the formation is excepted, there is more gravel in its upper than in its lower part. The arkose phase of the Pensauken stops promptly at an elevation of about 90 feet. This appears to have been the upper limit of aggradation by the Delaware.

About Rulons and Asbury Station the formation is at least 30 feet thick in places (Fig. 44). It must have been thicker still originally, for the top probably reached an altitude of 80 or 90 feet. West of Asbury Station its base runs down to 30 feet or so. Considerable patches of the arkose phase of the formation occur about Tomlins and Mickleton, and the non-arkose phase runs up to 100 or even 108 feet a mile east of Mickleton. The former phase is well developed about Clarksboro, where it is exposed in various pits.

Northeast of Swedesboro, some non-arkose gravels of uncertain age cap elevations at 114 and 115 feet, the gravel being cemented to some extent. The slopes between these hills and the arkose Pensauken at lower levels are nearly bare Cretaceous, and represent the old pre-Pensauken scarp, at the eastern border of the Swedesboro Plain.

East of Swedesboro, the non-arkose material classed as Pensauken occurs at various heights, and may be of different ages. If the arkose phase was built up by the Delaware to the present level of 80 or 90 feet, the contemporaneous deposits of Raccoon Creek should have risen perhaps to 100 or 110 feet at Mullica Hill. Most of the gravel and sands classed as Pensauken east of Swedesboro and north of the Raccoon Creek lie between the levels of 80 and 100 feet. The 114 and 115-foot patches east of

Rulons are hardly consistent with these levels. They probably are older, perhaps accumulations of postBridgeton-prePensauken age. In constitution these deposits consist of various combinations of sand and clay with a variable amount of gravel, all from formations up stream, or at elevations above the valleys.

The question concerning the Auburn, Asbury, and Mickleton patches is the following: Is the low-lying Pensauken surface (Auburn, 60 to 70 feet; Robbins Hill, 50 to 60 feet; Asbury Station, 70 to 80 feet; Mickleton, 60 feet) a surface of deposition (on the Swedesboro Plain), or a surface of degradation developed in the Pensauken below its original top? If the latter, the Pensauken here may have been a part, genetically, of the high-level Pensauken to the east. The evidence of this region, taken by itself, would look to the distinctness of the two phases of the formation.

If the Swedesboro Plain were built up to the level of the Woodstown Plain, it would at first seem that arkose should have extended onto the upper plain; but farther northeast the facts seem to deny the necessity of this conclusion. At Jamesburg, for example, the Pensauken was very thick, and was built up to the top of the corresponding upland; but only the lower part of the Pensauken at Jamesburg is arkose, and the higher, overspreading part is not. If a plain of erosion developed at 110 feet at Jamesburg, we should have the general relations of the Swedesboro region duplicated.

South of Wenonah, in the south bank of Mantua Creek, there is the following section, interpreted as Pensauken:

5) 3 feet reddish-brown clay.
4) 8 feet of gravel, sand and loam, interstratified.
3) 4 feet grayish sand, loam, and clay interbedded.
2) 3 feet gravelly and glauconitic sand and green clay.
1) 1 foot of iron-cemented conglomerate.
Cretaceous.

This section stands in a general way for the sections of the formations east of the arkose part.

Between Mantua and Coopers creeks.—The arkose Pensauken in this region appears to have been limited at the east by an old

scarp which was irregular, and much broken by the valleys which came down from the southeast. The existence of pre-Pensauken valleys coming down from the Woodstown Plain to the Swedesboro Plain is shown by the disposition of the Pensauken beds, which decline toward Timber Creek and Coopers Creek from both sides. This relation is less evident along Mantua Creek, and this valley was probably less developed. The arkose gravel went up the valleys of Coopers Creek and Timber Creek to a slight extent.

On the whole, the evidence seems to indicate that the pre-Pensauken surface had a well-developed drainage system, with valleys as steep-sided as those of today. There is one such steep slope where the Cretaceous surface falls away from 80 feet, near Bell Mawr Station, to 30 feet in the south bank of Little Timber Creek, a distance of one-fourth mile. At other places in the vicinity of Bell Mawr, the surface of the Cretaceous has equally steep slopes in such relations as to indicate that the slopes were pre-Pensauken.

Such evidence as is available indicates that the valleys of the tributaries were hardly as deep as now, while the valley of the Delaware was quite as deep. At Haddonfield, no Pensauken valley could have been lower than 40 feet, while at Wenonah, a valley may have existed down to 20 feet.

Between Mantua and Coopers creeks there are considerable areas of arkose Pensauken. The principal ones are southwest of Woodbury (west of Tatems at 50 to 70 feet), north of Woodbury (at 40 to 70 feet), at North Woodbury (at 40 to 70 feet), between Big and Little Timber creeks a mile south of Mount Ephraim (at 50 to 80 feet), and between Mt. Ephraim and Haddonfield, where it reaches up to 120 feet. In all these areas, the Pensauken rises to the east. The slope of the Swedesboro Plain was from 60 feet at the scarp in the vicinity of Woodbury, to 20 near the Delaware, and from 80 feet near Haddonfield, to 30 near the Delaware northwest of that point.

The Pensauken formation underlies the main part of Woodbury, and varies much in composition from point to point. Near Magnolia Grove, 7 feet of gravel and sand overlie 8 feet

of arkose sand. The stony matter of the upper member is coarse, up to 1 foot in diameter, and pebbles are not wanting in the lower, which is glauconitic. At other places in the vicinity much of the material is cemented by iron, or its grains and pebbles are coated with it. Near Mantua Creek, the arkose Pensauken occurs up to 76 feet near Tatems. This, with its position to the southwest, suggests the building up of the Swedesboro Plain by the Pensauken deposits to 70 or 80 feet.

To the east of these principal areas of arkose Pensauken, there are numerous areas of the non-arkose phase of the formation, the areas being poorly defined, and their correlation more or less uncertain. In general, this phase of the formation is higher than the arkose phase, and it is found neither in the valleys nor on the highest lands, but over areas of intermediate height. Not rarely it caps low divides and broad flattish areas above valley bottoms and valley terraces. In some places it occurs in elongate belts more or less parallel to the stream, as above Wenonah, above Blackwood, and above Chews Landing. The elongate patches in these positions suggest that the materials concerned are stream deposits, subsequently left as low ridges by the migration of the streams.

Proof that the arkose Pensauken to the west and the local Pensauken to the east were absolutely contemporaneous, is wanting. The two do not grade into each other, but their positions suggest their contemporaneity, especially if both are primarily the work of streams. Up the valley of Mantua Creek, just south of Wenonah, a considerable bed of gravel caps the low divide between Chestnut Creek and the main valley. The base of this gravel has an elevation of 50 to 70 feet. The top rises to 80 feet, and still higher toward Sewell. In position, these gravels are in harmony with those near Mickelton and Woodbury.

It appears that when Pensauken deposition began, the Swedesboro lowland was uneven, and that it was built up by the Pensauken arkose deposits to what is now the 80-foot level in the vicinity of Woodstown, and to 120 feet in the vicinity of Haddon-

field (Fig. 45, p. 136). This accumulation on the lower plain necessitated deposition on the upper (Woodstown) plain along the courses of the streams which crossed it.

The height of the Pensauken in the tributaries was influenced by its height in the main valley, and the tributary streams followed consequent courses over the newly deposited Pensauken of the main valley. The fact that the streams from the higher plains left them by pre-Pensauken courses shows that the Swedesboro plain was not built up to the Woodstown plain level.

Below Wenonah, patches of gravel occur up to 85–97 feet, which may be interpreted as local accumulations in Pensauken time or before. Other similar patches occur south of Mantua and west of Barnsboro. At Sewell heavy beds of gravel run down to 20 feet, showing a pre-Pensauken valley to this level, if this gravel is Pensauken, as interpreted. This is regarded as a deposit made by Chestnut Branch, which has shifted to the left since, leaving its old channel a ridge. The same thing is repeated north of Mantua Creek, and between it and Monongahela Creek. Here the divide is well over toward Monongahela Creek, with a steep slope toward that stream and a gentler, gravel-covered slope in the opposite direction. South of Hurffville, along Bethel Run, there are benches of gravel at 70 to 80 feet, but their age is not determinable. In this vicinity the distinctions between the Cape May and Pensauken formations are slight, both as to position and constitution.

Along Timber Creek, the phenomena of Mantua Creek are, in principle, duplicated. The Pensauken deposits 1½ miles south of Chews Landing are equivalent to those at Sewell, and the gravel is locally cemented. Similar phenomena are repeated between Greenloch and Blackwood, and again on the south side of the South Branch of Timber Creek, northwest of Turnersville. As at Hurffville, the Pensauken and the Cape May formations are here hard to separate, for the two overlap in elevation. Below Greenloch, the distinction between the two is not difficult.

Besides the larger patches along the streams, small hill-top patches occur. The Pensauken gravel of these patches is very

various, but the more striking contrasts come from the fact that some parts are much more cemented than others.

The vicinity of Blackwood in post-Bridgeton time, was developed to a fairly definite plain in which valleys 20 to 60 feet deep were cut. This was the topography when the deposition of the Pensauken formation began. Much of the so-called Pensauken on this plain may have been stream deposits made as the plain developed. Such deposits were followed by the deposition resulting from the filling of the Delaware.

Between Coopers and Rancocas creeks.—Between the lower ends of these creeks, there are two belts of Pensauken remnants, the one near the Delaware and the other a few miles farther back. In the belt nearer the river, the patches occur near Fish House (Beidemans-Bethel-Merchantville), southeast of Morris, about Cinnaminson (east of Palmyra), and smaller ones at and near New Albany, Fairview, Pavonia and Delair. At the highest, the surface of the formation in these patches reaches an elevation of 100 feet, as at Merchantville, while its base ranges in altitude from about 60 feet, down nearly to sea level. At Fish House, indeed, it probably goes down to sea level, under younger beds. The general relations of the Pensauken in this latitude are shown in Figs. 45, 46 and 47 (p. 136).

The patches of the second belt occur north of Ellisburg and southwest of Moorestown, between the north and south branches of Pensauken Creek, at Moorestown, and thence north to Swedes Run, and northeast nearly to Rancocas Creek. The elevation of the surfaces of these remnants is about the same as that of the patches to the west, but their bases are not so low, rarely below 50 feet. The altitude of the Swedesboro Plain here was about 70 feet, a level which extended well up to the Delaware.

These two series of remnants are so related to each other and to drainage lines as to show that they were once continuous, and that their isolation is the result of stream erosion. The smaller streams, such as Pompeston Creek and Swedes Run, have not dissected the area to the extent the larger streams have.

The material of the formation nearer the Delaware is more gravelly, that of the remnants farther from the stream more

sandy. In the latter, most of the gravel is near the top. In the former, gravel predominates over sand, and considerable beds of arkose sand free from gravel are rare.

For the eastern patches, the material near Ellisburg is characteristic. Here, at the top (at the 100 foot level) is 4 feet of gravel, with sand and loam matrix. The whole is very compact, and its stratification irregular. Beneath the gravel there is at least 18 feet of arkose sand, yellow to white in color, compact and well stratified, with an occasional seam of pebbles. Hills at slightly higher levels (102 feet, 108 feet) have caps of gravel, apparently the upper member of the formation, resting on Cretaceous. These hills appear to represent about the upper level of Pensauken deposition here.

In the large area north and northwest of Moorestown and Hartford, the upper part of the formation has more gravel, and the lower part more sand; but at the very base, gravel is likely to occur. There are many pits where the sand and gravel are worked for road material. One pit shows:

3) 2 feet loam and sand with quartz pebbles.
2) 8 feet coarse sand, more or less cemented by iron oxide.
1) 6 feet sand and fine gravel, well stratified, with occasional bowlders 1 foot in diameter, and with bits of red shale.

In the more westerly areas, the difference in constitution is brought out by a few sections. Thus west of Merchantville, a section showed 7 feet of compact gravel and arkose sand of a brownish color, above 4 feet of similar material of lighter color.

At Fish House and Delair extensive excavations have shown a heavy bed of black clay (Fig. 49), overlain in places by typical Pensauken gravel, and underlain by gravel of Pensauken type, quite like that at low levels in Philadelphia (p. 106). The clay contains unio shells, one species of which still lives in the river in the vicinity.

South of Morris Station, on Pensauken Creek, the place which gave name to the formation, exposures of the formation over the Cretaceous clay are numerous. The following is a typical section:

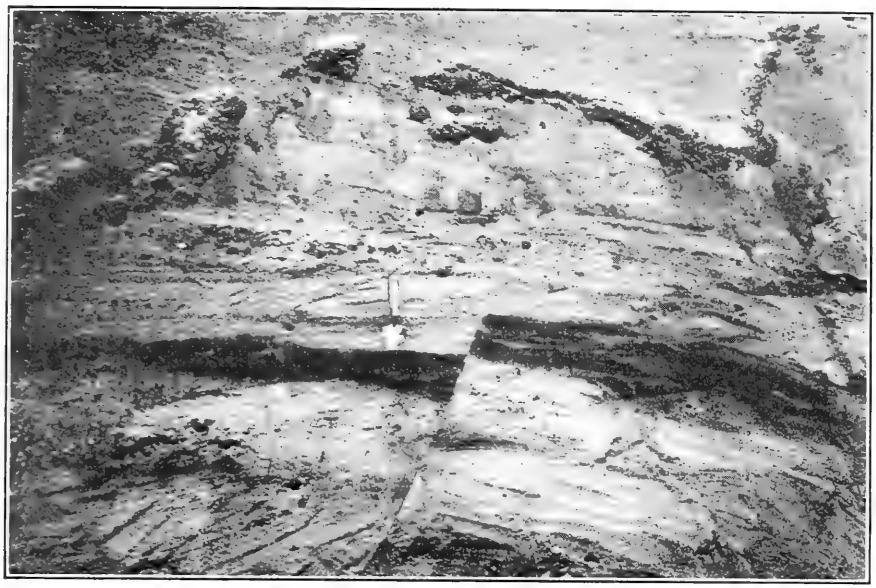


Fig. 41.

Pensauken formation west of Woodbridge, Middlesex County. Note the fault with displacement of 6 inches (to the right of the trowel).

Fig. 49.

Black clay at Fish House, Camden County. Twenty feet of black clay overlying Pensauken sand (not shown in the photograph). Pensauken gravel overlies this clay in the immediate vicinity, although not in the section here reproduced. The clay contains numerous unio shells.

3) 8 feet coarse gravel and brown sand and loam, compact.
2) 16 feet coarse brownish sand of arkose type.
1) ½ foot coarse gravel and cobbles.

Pebbles and cobbles of crystalline rock are abundant in the gravel, and most of them are so decomposed as to be easily crumbled in the hand. Most of them are well rounded. Bits of red shale of Triassic origin are as abundant as those of all sorts of igneous rock, and are mostly in well-worn disc-shaped pieces; but there are occasional angular pieces of larger size.

In the area about Cinnaminson, the base of the Pensauken has an average altitude of about 60 feet; but at the west it is as low as 30 feet, and elsewhere locally as high as 70 feet, thus showing considerable irregularity. From Cinnaminson the base declines 40 feet in a mile to the northwest, toward Pompeston Creek.

East of Palmyra an exposure in the hill on which the Riverton waterworks stand, a gravel pit at 70 feet, shows 75 per cent. of the stony material of the gravel to have a diameter of less than 1 inch, though cobbles 3 inches in diameter are common. Quartz is the chief constituent (90 per cent.), while red shale and granitic material make about 2 per cent., and chert and quartzite the remainder. The gravel is very compact, and has little sand. In the vicinity, however, other exposures show arkose sand with but little gravel. Near North Pennsville one section showed some clay associated with the sand and gravel. This recalls the phenomena at Fish House.

Near New Albany, the hilltop remnants of the Pensauken occur at elevations which range from 80 feet for the base at New Albany, down to 50 feet at Hunters Hill, 1½ miles to the northwest. At Fairview, the range is from 70 to 90 feet.

The arkose material came down Delaware River, and built up the lowland. This phase of the formation is limited southeastward by an old scarp at some points, while at others the scarp was broken down, and the northward gravel went up the side valleys a little to the southeast of the general line of the scarp, as in the vicinity of Moorestown.

Southeast of the scarp, the old Woodstown Plain was 30 to 40 feet higher than the Swedesboro Plain. It was cut by valleys

30 to 50 feet deep, which interrupted the continuity of the scarp. The arkose phase of the formation did not extend beyond the Swedesboro Plain.

The Mount Laurel flats.—In contrast with the area southwest of Coopers Creek, a broad area about Mount Laurel and Marlton is low and free from any surface material which can be referred to the Pensauken formation (Fig. 47, p. 136). It is probable that the formation was once here, and that it has been eroded away.

The altitude of the surface in this area is below the level of the Pensauken to the west, much of it considerably below. Various elevations in the region at heights of 80 to 90 feet have a scattering of surface pebbles which suggest the former presence of a gravelly formation. Such suggestions of the pre-Pensauken plain as the surroundings afford would place it at 80 to 90 feet. If this is correct, the present lowland about Mount Laurel, at 30 to 60 feet, is of post-Pensauken origin. This is a singular feature topographically, because the area is distinctly below the general level of the land between it and the Delaware, through which the degrading streams must have passed.

The explanation of the Mount Laurel lowland is probably to be found in two principal facts: (1) The Cretaceous beds which outcrop here are more easily eroded than those which outcrop to the west where the surface, except for the valleys of Pensauken and Rancocas creek, is higher; and (2) the Pensauken once deposited in the area of the present flats was possibly finer and thinner than that deposited by the main stream.

Southwest of Coopers Creek, the area was not equally degraded in pre-Pensauken time, perhaps because the corresponding bed of the Cretaceous is much thicker there than to the northeast. Further, Rancocas Creek seems to have been the largest of the streams from the east, and for that reason to have been most efficient in erosion.

Vicinity of Philadelphia.—In much of Philadelphia the base of the Pensauken is below 40 feet, and in places as low as sea level, and the low-lying part of the formation is somewhat different from the part at higher levels. In the city, the Pensauken

material at 60 to 120 feet is similar to that at corresponding elevations east of the river. That is, it is principally of arkose sand, whitish to yellowish and brownish in color, with seams of pebbles which develop, locally, into beds. The pebbles are on the whole well worn, and many of them well rounded. Some of them are disc-like. Bits of granite and shale are common, and locally abundant. The sandy part of the formation has much resemblance to the decomposed gneiss of the region.

The part of the formation below 40 feet is more gravelly. Sand is subordinate, and not notably arkose. Among the stony materials, angular to subangular pebbles of quartz, quartzite, and sandstone predominate. Bowlders and cobbles are more common than at higher levels, and pieces of crystalline rock are more common than above. Shale occurs also, but is less well rounded than at higher levels. This type of gravel has not been seen on the east side of the river, and it has not been seen directly beneath the normal arkose Pensauken; but its relations seem to imply that it is the basal part of the valley filling, over which the Pensauken proper was deposited later.

Between Rancocas and Crosswicks creeks—Delaware phase.—The two phases of the Pensauken are present here in the same relations as farther south. The pre-Pensauken scarp separating them extends from southwest to northeast through Rancocas, Jacksonville, Columbus, and Mansfield, to Extonville, and is essentially coincident with the outcrop of the Englishtown sand (a bed of the Cretaceous), the upper part of which is more or less cemented by iron. The scarp was 20 to 50 feet high at the time of Pensauken deposition. The general section for the region is shown in Fig. 50 (p. 136).

Pensauken deposition here followed the lines already sketched. That is, it began in the channel of the Delaware, and spread back over the valley lowland to the scarp separating the Swedesboro and Woodstown plains. This aggradation in the main valley affected the tributaries, causing them to aggrade their valleys with material brought in from the southeast. Deposition in the tributary valleys appears to have kept pace with that in the main valley.

The larger remnants of arkose Pensauken occurring at the surface in this area lie at and northeast of Rancocas (70 to 90 feet), on the divide between Mill Creek and Assiscunk Creek (60 to 109 feet), in an area about Deacons, on the divide a mile or so northwest of Jacksonville (70 to 103 feet), on the divide east of Bustleton (70 to 109 feet, and east of Bordentown (80 to 120 feet). Smaller areas occur east of Kinkora (above 80 feet), at Mansfield (above 80 feet), a mile east of Fieldsborough (above 80 feet), and a mile southeast of Crosswicks (above 90 feet). In most of these places the formation caps low divides, its base having an elevation of 70 to 80 feet; but in two places it is known to run down much lower. One is at Rancocas Creek, south of Rancocas, where its base is as low as 20 feet locally; the other is southwest of Beverly, where it has been seen in excavations beneath the Cape May formation, where its top has an altitude of 20 feet, and its base probably about 10 feet. Normal Pensauken occurs here, with pebbles of decomposed crystalline rock, red shale, trap, etc. One bowlder of trap 3 feet in diameter was seen. The matrix is arkose sand. The low altitude of the remnant here is consistent with the position of the base of the Pensauken at Rancocas and Fish House.

At and near Rancocas, the eastern edge of the Pensauken area appears to lie against the old scarp above the Swedesboro Plain. The material of the formation here is finer than the average, and contains less foreign (northern) material.

Coarser phases of the formation are seen north and northwest of Deacons, in pits where the depth of the Pensauken material is 6 to 10 feet,—probably the lower part only of the formation as originally developed. Its later, upper, and generally finer phase has been removed.

In the area about Deacons Station (Fig. 48), the formation occupies the divide between Assiscunk and Mill creeks. The higher points in this area are to the east, and reach an altitude of 106 to 108 feet. The materials are largely of local (from the east) gravel, including ironstone, quartz, and chert. Ironstone in large pieces is most common at the base of the formation, along with the northern arkose material, and the red shale, which goes

with the latter generally. The ironstone masses were perhaps residual on the surface when the northern materials were deposited on and among them. The upper part of the Pensauken here is not arkose. It would appear that the lands to the southeast must have been higher than now, or at least must have yielded more sediment than now, to have furnished the Pensauken material above the basal layer.

At Deacons Station, extensive excavations reveal the presence of large bowlders (up to 4 feet in diameter) of crystalline rock, and slabs of red and black shale 1 and 2 feet in diameter. At this place, the arkose phase of the formation is interstratified with the non-arkose phase. The sources of the materials therefore alternated from time to time, while the lower 10 feet was accumulating. The upper part here is largely arkose. The eastern edge of this area marks the approximate southeastern border of the Delaware (arkose) phase of the formation. Of the coarse material (cobble size and larger) in the formation here, sandstone predominates greatly over all others, in most places. Granite bowlders up to a foot in diameter are decayed and soft to the core. Of the finer gravel, quartz is the leading constituent.

A good exposure half a mile southeast of Deacons showed an abundance of granitic and other northern material. Red shale and Stockton sandstone are readily recognized, also slabs of black shale, similar to that at Milford. Ironstone slabs up to 6 feet in diameter occur here,—not masses formed *in situ*, but transported masses showing some evidence of wear. At other pits in the vicinity, notably 1½ miles southeast of Deacons Station, there are seams of clay in the formation, and pellets of clay, arranged in seams. The section here shows 2 feet of compact arkose sand and gravel, under 8 feet of glauconitic sand. The material is coarser at the west and finer to the east, and glauconite, essentially absent at the west, is abundant at the east.

Northwest of Jacksonville, as at many other places, the base of the formation is uneven enough to show that the underlying surface had considerable relief when the formation was deposited.

If the Delaware Valley to the west was built up to a level

which is now 100 feet above sea level, as seems certain, it would seem that Assiscunk Creek should have gone south to Rancocas Creek, if the divide between them had not been higher than now. The fact that it went westward indicates that the divide was higher than now.

The remnants of the formation within a few miles of Riverside suggest a measure of post-Pensauken erosion. At New Albany, remnants occur at 100 feet, and others in the vicinity of Cinnaminson and Deacons, have about the same elevation; the surface here must have been built up to about this height in Pensauken time. At Beverly the base of the formation has an altitude of not more than 10 feet. These figures suggest an original thickness of 90 feet or so over what were the deeper valleys, and at least 30 feet over the pre-Pensauken plain which is now at 70 feet. From these facts and the present fragmentary condition of the formation, some idea may be had of the erosion which has taken place.

In the vicinity of Bustleton, pits reveal the structure and constitution of the formation well (Fig. 31, p. 78). The material ranges from coarse, with occasional bowlders 2 and 3 feet in diameter to fine, with nothing coarser than pebbles. In some of the pits the sand is arkose, while in others it is not, or not uniformly so. The structure, too, is variable, suggesting waters of varying strength of current. Within the area there is the same evidence of transition from the northwest phase to the southeast phase that was noted about Deacons.

A mile and a half west of Columbus is a partially isolated area which is topographically the eastward continuation of the Bustleton area. It is covered with a thin bed of gravel, which includes blocks of conglomerate. This is a non-arkose remnant, possibly antedating the deposition of the arkose phase nearer the Delaware.

At Florence there is a small area of Pensauken, which has an altitude of 75 feet to 80 feet. This remnant, like all others near the Delaware, is arkose. Its position indicates that the main valley of the Delaware was not just where it now is in pre-Pensauken time.

There is a considerable area of Pensauken north of *Three Tuns,* and a mile east of Kinkora. The material here is very similar to that at Bustleton. Bowlders 2 to 4 feet in diameter are to be seen about the border of the area, and it is inferred that they came from the base of the formation, appearing now where the Pensauken has been removed.

At Mansfield (Fig. 50) and northwest there is a large patch of Pensauken whose base has an elevation ranging from 110 feet at the east to 90 feet at the west. The height of the eastern part here indicates that deposits reached up to the top of the scarp, and perhaps overlapped it. The crystalline rock material is confined to the lowermost 1 or 2 feet of the formation.

Southeast of Mansfield Square is a hilltop (108 feet) cap of the non-arkose phase of the formation. Its topographic position leads to its correlation with the Pensauken. Other small patches of gravel between Mansfield and Three Tuns have characteristics similar to those of the larger areas. Such an area occurs at Sharps Station, and another a mile to the northeast.

A large area of Pensauken occurs east of *Fieldsborough,* but exposures were poor when the region was seen. Enough was seen to show that the patch contains much coarse material. The remnant has a surface altitude of about 90 feet, and it is 10 to 20 feet thick.

The area east of Bordentown occupies the divide between Blacks Creek and Crosswicks Creek. The east part of the formation here lies at the base of the old scarp, as at some of the localities farther south. Arkose material rises to 110 feet at least, and perhaps higher. Northern material is more common in the lower than in the upper part of the section, but is not restricted to the bottom. There is some cementation. In the area as a whole there is, as at other points to the south, a distinct transition from mostly arkose at the west, to mostly non-arkose at the east, at slightly higher levels.

A mile west of Crosswicks, on the Bordentown road, a well section seen was as follows:

2) 4 feet gravel and loam.
1) 20 feet coarse sand, with gravel and cobbles at base.

On the whole, the material of the area is chiefly coarse arkose sand, with coarse gravel, cobbles and even bowlders at the base.

In the vicinity of Crosswicks there is a considerable area of arkose Pensauken south of the creek. The character of the material is like that at Bordentown. Its base is at such elevations as to indicate that a valley occupied approximately the site of the present Crosswicks Creek in pre-Pensauken time.

In general the Pensauken is coarser, and contains more northern and arkose material near the Delaware, and is finer, with less arkose material, farther back from the river. At the east, there is local material only; at the west, northern material chiefly; and in a belt between, the two are somewhat mingled and interbedded. The interbedding and intermingling are chiefly along the southeast border of the Swedesboro Plain, near the base of the old scarp which marked its southeastern limit. The Swedesboro Plain here has an altitude of 50 to 80 feet, and is 20 to 40 feet below the scarp to the southeast. The structure of the arkose phase is not unlike the structure of the valley train of the last glacial epoch, above Trenton. The Delaware phase of the formation spread 2 to 4 miles from the present stream. A similar condition of things existed on the west side of the Delaware.

Between Rancocas and Crosswicks creeks; non-arkose phase. —East of the arkose phase of the Pensauken between these creeks, there are many patches of gravel and glauconitic sand, representing the non-arkose phase of the formation. They occur at elevations similar to those of the arkose phase, and slightly higher. Some of the larger areas are at Columbus, on the divides between Jobstown, Juliustown, and Arneys Mount, and on those about Georgetown. The gravel is thin, 4 feet being an unusual thickness, and the material is mostly quartz and ironstone. Glauconitic sand and loam are more abundant than gravel. The altitude of the bases of these patches ranges from 50 feet up to 130 feet. Their correlation with one another, and all with the Pensauken, is open to question, but many of them are at the level of 80 to 90 feet, which makes their reference to the Pensauken reasonable.

A cross section drawn from Timbuctoo (a mile west of Mount Holly) to Chesterfield, crosses six of these patches of uncertain Pensauken, with their bases ranging from 55 to 85 feet. All of them lie on or close to the outcrop of the same bed of the Matawan group. Along a parallel section farther west, through beds of the Delaware phase of the formation, the bases of the Pensauken remnants have elevations of 65 to 85 feet. The first series of beds therefore corresponds fairly well with the Pensauken remnants in elevation.

If a section from Rancocas village to Crosswicks village (farther from the Delaware) be so drawn as to include the bases of various Pensauken remnants, these bases have slightly greater altitudes, 80 to 108 feet. That is, the bases of the eastern beds of arkose Pensauken are higher than the bases of the *non-arkose* remnants still farther east. But the belt from Rancocas to Crosswicks, where the bases are highest, is the belt where the most resistant member of the Matawan formation comes to the surface. It is believed that this outcrop had not been brought down to the pre-Pensauken peneplain, when the Pensauken deposition began.

It is certain that the region to the west was built up to the level of the Rancocas-Crosswicks section, and it is probable that the region to the east was equally aggraded. On the other hand, it is conceivable that this low-level belt (Timbuctoo to Chesterfield) was not built up to the level of the Delaware plain in the Pensauken epoch. If so, a marsh or even a lake might have developed east of the main belt of Delaware deposition. Perhaps the green loams are a product of this condition. On the whole, however, the flat low lands northeast of Mount Holly are probably to be explained the same as those about Mount Laurel.

West and northwest of Juliustown, Pensauken gravels, etc., cap divides between the branches of Barkers Brook, at levels of 100 feet and less. This area has 4 to 8 feet of gravel and sand, lying on Cretaceous. The stony material is quartz, chert, and ironstone, not very distinctive. The correlation of these areas is doubtful, and they are regarded as Pensauken on the basis of position only.

North, west, and south of Fearings Mount, hilltop patches of gravel at 120± feet are to be correlated with each other, and perhaps with the Pensauken. The amount of gravel is small, but perhaps enough to suggest the approximate altitude of the Woodstown Plain. At other places in the vicinity, bare Cretaceous appears at about the same level. Glauconitic loam is more conspicuous than gravel at the surface in much of this area. The gravel is limited to the contact of the Cretaceous and the sandy loam above. The slopes above and below 120 feet are more commonly bare Cretaceous than are surfaces at about that level. Similar areas occur on the divides west of Jobstown.

In the vicinity of Georgetown are numerous small patches of gravel classed as Pensauken. These range up as high as 140 feet, but are thickest somewhat lower. Half a mile south of Georgetown a pit shows 6 to 8 feet of gravel, with a mixture of glauconitic sand and marly loam. Seventy-five to ninety per cent. of the gravel is of ironstone, mostly fine, but with some coarse gravel and cobbles. In the sand of the formation, grains of the sort common at the contact of the Navesink and Mount Laurel formations are abundant, showing the source of same at least of the material of the sand. Other exposures of gravel west of Georgetown show the same general features. All about here, the matrix of the gravel is glauconitic sand and marly loam. The ridge northwest of Jobstown, and between Barkers Brook and Assiscunk Creek has a heavy cover of it. The next divide to the southwest has less, but enough to conceal what is below, so as to make correlations difficult. Glauconitic sands in the surface deposits are also common over most of the area between Mount Holly and Georgetown, where they run up to 120 feet, and on Arneys Mount even higher. A similar glauconitic mantle appears in the valley of the Rancocas south of Arneys Mount, and in the valleys of Crosswicks and Blacks creeks to the northwest of Georgetown.

This surface green loam is doubtless connected in origin with outcrops of Cretaceous beds of marl, but the conditions of its deposition are not altogether clear. It is conceivable that the upper parts of the valleys in this region were not aggraded as

fast as the lower parts, and so in the more or less ponded waters, the marly material from the uplands accumulated in marshy tracts. This hypothesis is, however, not altogether satisfactory, for distinctive lacustrine deposits are wanting.

Along the Assiscunk Creek and Barkers Brook, in the vicinity of Jobstown and Jacksonville, glauconitic sands are accumulating as ridge-like beds bordering the present streams, which head back in the marl beds, whence they derive their greensand. During floods, these streams deposit the greensand on their flood plains several feet above the ordinary stages of water. When the flood-plain becomes dry, the greensand is blown about, in many cases to higher levels, and piled up into low dune ridges. The ridges now seen are slight, rarely more than 3 or 4 feet high. It seems therefore quite possible that floods and winds may have been important agents in the distribution of the greensand loams. It is also probable that they did not all originate in one way or at one time.

Along Blacks Creek there are numerous patches of gravel between Jacobstown and Chesterfield which may or may not be of Pensauken age. Some of them appear to be younger. They are characterized by local (southeastern) gravel, in which ironstone and glauconitic sand are conspicuous elements. Materials from the Navesink marl and the Kirkwood sand can be recognized distinctly in some places. Glauconitic loam overlies gravelly, glauconitic sand in many places. On the whole, the sections along Blacks Creek above Chesterfield show more gravel up stream, and less below.

Along this creek there are gravels and sands of undetermined age. Some of them seem younger than the Pensauken, and older than the Cape May. Gravels of intermediate age are of course quite possible. There are small beds of gravel classed as Pensauken on benches at an altitude of 100± feet, a mile or so south of Chesterfield.

Northeast of Woodstown, the Woodstown Plain appears to have terminated somewhat abruptly against a scarp such as that now seen east of Juliustown, west of Fountain Green, at Spring-

field and Jacobstown. The isolated hills at 125 to 130 feet, south of Chesterfield, are perhaps outliers of this scarp.

CROSSWICKS CREEK TO RARITAN RIVER.

General statement.—From Allentown and White Horse northeast to South River, the Pensauken forms a nearly continuous cover, being interrupted only by the valleys of the larger streams flowing northwest,—Pond Run, Miry Run, Assanpink Creek, Bear Brook, Millstone River, Cranbury Brook, Lawrence Brook and some of its branches. Newtown, Hamilton Square, Dutch Neck, Hightstown, Cranbury, Prospect Plains, Dayton, Dunhams Corners, and Hardenbergh Corners, are on the Pensauken plain; Princeton Junction, Monmouth Junction, and New Brunswick are on its northwestern border; and Jamesburg and Old Bridge, on its southeastern border (Fig. 55).

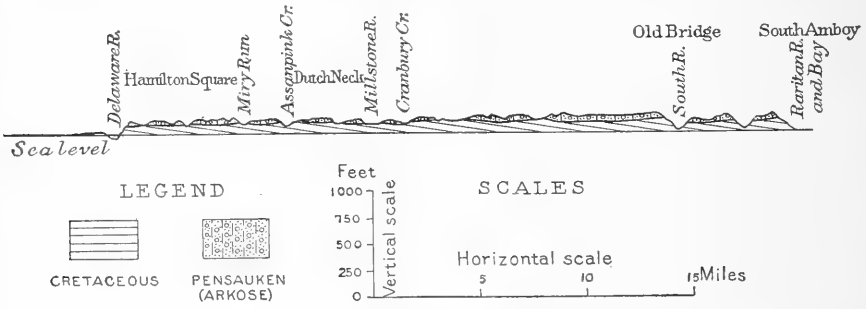


Fig. 55.

Section through Hamilton Square, Dutch Neck and South Amboy, showing relations of the Pensauken formation.

Northeast of Bordentown, the two-fold division of the pre-Pensauken surface (Swedesboro and Woodstown, p. 91) has not been recognized, and the scarps to the southeast of the main Pensauken area were less well defined. In place of a well-defined scarp, there were numerous headlands projecting out from the southeast. These headlands were probably the remnants of a scarp dissected by erosion. To the southwest, where the scarp (the outcrop of the Englishtown sand) was more continuous, it limited the arkose Pensauken. To the northeast,

where it was not continuous, the broad valley of Assanpink Creek extended eastward far beyond the line where the scarp would have been, and the arkose Pensauken was carried up this valley to New Sharon and beyond. The northern material (arkose, red shale, etc.), is chiefly at the base of the formation, nine-tenths of it probably in the lowermost 5 feet. It is clear that the northerly material was the first to come into the region, but it soon gave place to local material from the southeast. The belt within which arkose Pensauken occurs here is greatly widened, as compared with the area farther southwest. The great widening occurs at Crosswicks Creek, and the arkose phase of the formation extends east to Extonville and New Sharon.

Near Crosswicks and Doctors creeks.—Between Crosswicks Creek and Doctors Creek, south of Allentown, there is a large area of Pensauken, the surface of which has a maximum altitude of 126 feet. Its base has an elevation of about 60 feet near the stream, and about 90 feet back from it. The pre-Pensauken valley here appears to have been rather wide, and shallower than the corresponding valley of the Rancocas. The formation here has a thickness of about 30 feet. A bed containing coarse cobbles probably lies at its base, for about the borders of the area, cobbles appear where the body of the formation has been removed. Exposures show the usual arkose gravel and sand on Cretaceous clay. A mile south of Allentown, arkose sand occurs up to the top of the 126-foot hill. The surface of part of this area is mantled with eolian sand and loam, which conceals the true Pensauken material beneath.

In the village of Allentown, what appears to be Pensauken gravel has been seen poorly exposed in the south bank of the creek. The material is more or less cemented at the level of the pond, 60 to 65 feet. This and some other exposures farther down the creek suggest that Pensauken material may lie below the Cape May deposits here.

There is a considerable area of Pensauken east and northeast of White Horse, rising above the 90-foot level. It rests on the Raritan formation, as seen in numerous exposures. Its surface declines to the northwest, and the formation passes beneath the

Cape May formation at an elevation of about 60 feet. The Pensauken is traceable westward by means of excavations, and in ravines, to within three-fourths of a mile of the Delaware, where its upper surface, beneath the Cape May (Trenton gravel) formation, has an altitude of 20 to 30 feet. Pits south and west of White Horse show the material to be very compact, but not very coarse gravel, of a reddish-yellow color. Large cobbles and even bowlders occur on the surface, doubtless left there by the removal of part of the formation. The surface here is characterized by many undrained hollows, comparable to those in the surface of glacial drift, where its topography is relatively plane.

The Mercerville-Robbinsville-Allentown area.—The surface of this area has an altitude ranging from about 100 feet at the west, to about 140 feet (maximum 153 feet) at the east. At the west the base of the Pensauken has an altitude of about 80 to 90 feet, but is as low as 70 feet, or possibly 60 feet, at some points near pre-Pensauken valleys.

The base rises to 90–95 feet at Robbinsville, and 120–130 feet at points on the eastern border of the area, near New Sharon. Where the Pensauken occurs at the lower levels on slopes, it is possible that it has been displaced down slope since Pensauken time. The base appears to remain relatively low (90 to 95 feet or less) to a point 2½ miles east of Robbinsville, where it rises rather promptly to 130 feet along the site of what was probably an old headland extending northwest from Egg Tavern.

In this general area the Pensauken is arkose, and contains bits of crystalline rock, shale, etc., as normally. It has a depth of 30 or 40 feet, maximum, but its average is much less.

A good exposure on the railway near Robbinsville showed:

3) 2 feet of quartzose sand and loam.
2) 6 feet of horizontally stratified gravel and sand, with pockets of 3) sunk into its surface.
1) 7 feet of coarse arkose sand, somewhat cross-bedded, with bottom not seen.

Two miles southwest of Robbinsville, in the north bank of Back Creek, at 60 feet, the material is much coarser, cobbles, and

small bowlders (up to 1 foot) being abundant. These cobbles and small bowlders have been gathered in large numbers along some of the fences. Between Robbinsville and Yardville, similar stones are common over the surface. They are the relics of Pensauken that is gone.

The characteristics of the formation in the vicinity of Robbinsville hold to the northwest; but the materials become coarser in that direction, and the proportion of granitic and Triassic material increases, though not uniformly.

A mile and a half south of west of Hamilton Square, at the road corners, there is a bowlder 4 feet in diameter. The surface hereabout is characterized by occasional undrained hollows, drift fashion. Raritan clay lies close beneath, and its movement, resulting from its plasticity, is perhaps responsible for this element of the topography.

Between Assanpink Creek and Miry Run.—The Pensauken here has a surface altitude ranging from 70 feet or so up to 100 feet or slightly above. Locally, the formation is hard to distinguish from its Cretaceous base, especially where the latter is sand.

Shrewsbury, Wrightsville, and New Sharon.—About Shrewsbury and Wrightsville there are, within a few miles' radius, a number of gravel-capped hills. The gravels are of southeasterly origin, and their age is somewhat uncertain. Knapp regards them as probably Pensauken, but they may be older. The hilltops about Shrewsbury range from 140 to 155 feet, and those about Wrightsville up to 190 feet. Larger areas of possible Pensauken occur just south of Shrewsbury and Egg Tavern, and at Wrightsville. These larger patches are on slopes, and are younger than the hilltop caps. Their exact age does not appear to be determinable. If the hilltop caps are Pensauken, these are younger; if the hilltop caps are older, these may be Pensauken.

On the divide at Davis Station, and extending both east and west, is a body of non-arkose Pensauken at an elevation of 140 to 148 feet. One section seen here shows:

2) 2 feet of slightly gravelly loam.
1) 3½ feet of indistinctly stratified gravel and sand. Some layers have much loam as a matrix for coarse sand, others are chiefly of loam or marly loam; glauconitic.

The stony material is made up of quartz, chert, and ironstone. Other sections near vary but little from the above. Other patches of gravel regarded as Pensauken occur at Cream Ridge (150± feet) and east of Imlaystown, at about the same elevation.

Near New Sharon there are two patches of Pensauken. That east of the railway is mostly non-arkose, that west of the railway arkose. Their bases are at about 90 feet, and their surfaces run up to about 130 feet.

Trenton and vicinity.—A mile or less east of that part of Trenton known as Chambersburg, and also 4 and 5 miles northeast of Trenton, there are small areas of Pensauken rising up through the Cape May formation. The tops of these areas, one of which is in the Fair Grounds, are above 60 feet, the upper level of the Cape May, represented here by late glacial gravels and sand. Pensauken underlies considerable parts of the Cape May formation about Trenton, running down to levels as low as 20 feet, and probably down to 10 feet (Fig. 33, p. 54).

North, northeast, and northwest of Trenton, there are numerous areas of Pensauken resting on the Newark series. They cover much of the area below an elevation of 120 feet, in the area roughly outlined by Trenton, Asylum Station, Lawrenceville, and Princesville. The northwestern border of the Pensauken here is well defined, just as its western border is at Philadelphia, where the edge of the formation is on gneiss and schist.

The base of the formation in these areas is 80 to 90 feet above sea level at the south (in the north part of Trenton), and rises to 120 to 130 feet to the north and northeast. Its remnants in this vicinity, considered in connection with those to the southeast, show the existence of a pre-Pensauken valley in the general position of Assanpink Creek, at or near the southeast border of the outcrop of the Newark series. This valley was as low as the present 20-foot level at Trenton (possibly lower), and probably below 30 feet at Bakers Basin, 6 miles northeast of Trenton.

The valley was wide, and its southeastern slope was gentle, declining from an elevation of 80 or 90 feet at Edinburgh and Hamilton Square at the southeast, to 30± feet at Bakers Basin, and 10 or 20 feet at Trenton, at the northwestern edge of the Cretaceous terrane.

The upper limit of the formation northeast of Trenton is at about 130 feet, along a fairly well defined line, and this appears to have been its original upper limit. Northwest of the 130-foot contour, the Newark shale surface rises somewhat promptly to 200± feet. There appears to have been a somewhat definite though low and gentle scarp at what is now the level of 130 feet, when the Pensauken gravel was deposited. Below this scarp there was an ill-defined bench, whose northwestern margin has now an altitude of about 120 feet, and whose southeastern margin had an elevation of about 90 feet. On this bench, Pensauken gravel accumulated.

At higher levels (up to 190 or so) in this vicinity, as about Ewingville and between Pennington and Lawrenceville, there are cobbles and even good-sized bowlders over the surface. These are interpreted as relics of an older formation, perhaps the Bridgeton, which once overlay this region, but which is now gone except for these relics. These bowlders and cobbles are somewhat different from the coarse materials of the Pensauken. Stated in other terms, the Pensauken contains certain types of stony matter not known at the higher levels.

The shale surface beneath the Pensauken north of Trenton does not show valleys comparable to those of the Cretaceous surface beneath the Pensauken to the southeast. The 120-foot bench northeast of Trenton is probably very definitely related to the 90-foot base of the Pensauken in the vicinity of Allentown, Newtown, Hamilton Square, and Edinburgh. If these two levels in these localities are parts of one plain, the Cretaceous part of the plain was 5 miles wide southeast of Trenton, and 8 miles wide between Princeton and Hightstown. The corresponding bench in the Newark was much narrower, 3 miles at a maximum, and in some places as little as 1 mile.

The material of the Pensauken formation north and northeast of Trenton is essentially the same as in the areas north of Crosswicks Creek, already described. The stony material is chiefly of quartz and sandstone, with a little Newark shale and a little crystalline rock. The amount of shale present varies much from point to point.

On the hypothesis that the Pensauken is a marine formation, the 130-foot line marking its upper limit was the shore line of the sound which extended from Trenton to Raritan Bay. In this case, the shore gravels should have been largely of red shale. While this is true in spots, it is not the rule, and though the constitution of the gravel is perhaps not altogether decisive, its suggestion is rather that the gravel along the original border of the formation was not derived by wave action from a shore of shale.

Southeast of Asylum Station, some sections of Pensauken show much clay, mingled with plentiful cobbles and bowlders, among which brownish quartzitic sandstone, white conglomeratic quartzite, and Stockton conglomerate are most conspicuous.

A mile and a half south of Lawrenceville, a Pensauken section shows:

3) 3 to 4 feet of gravel, the stony matter imbedded in clay and loam.
2) 1 foot of red shale gravel, little worn.
1) ½ to 2 feet of red shale gravel, mixed with quartz, very compact.

In the uppermost member, the stony matter is made up of about one-third chert, one-third quartz, with sandstone, quartzite, and shale in decreasing proportions in the order named. At numerous points in the area between Trenton and Princesville, the Newark conglomerate, when decayed, has a superficial resemblance to the Pensauken, and might be mistaken for it on hasty inspection.

At Clarksville there is an area of Pensauken on the divide between Port Mercer and Lawrence Station. Locally at least it contains much red shale. Similar gravels occur at other points to the northwest, but in none of these places do the gravels contain more red shale than at one point south of New Sharon, 9

miles from the nearest shale outcrop. Conditions of deposition were therefore such as to permit the deposition of red shale gravel, in quantity, at this distance from its source. The shale could hardly have been carried across a sound, unless by floating ice.

Between Assanpink Creek and Millstone River.—In the vicinity of Princeton Junction, the crystalline rocks are but thinly covered with Pensauken, the contact being at an elevation of about 90 feet. To the south the Pensauken is thicker, covering uninterruptedly a broad area which extends through Dutch Neck to Edinburgh, Windsor, and Allens Station. From an elevation of about 90 feet at Princeton Junction, its surface rises to an elevation of about 150 feet near Allens Station. Only at the extreme southeast, however, is much of the surface above 130 feet.

Within this area, the lowest level of the base of the formation is not at the contact of the Cretaceous with older formations, but along a line running northeast from Mercerville, through Dutch Neck and Grovers Mill, to Plainsboro. Along this line the base of the Pensauken is below 70 feet at many points, and perhaps all the way. This would seem to place the lowest part of the pre-Pensauken surface a mile or two southeast of the surface contact between the Cretaceous system with the Newark series.

To the southeast, about Newtown, Windsor, and Hightstown, the drainage was from the southeast to the northwest. It is clear that between these points and the northwest edge of the Cretaceous, these streams must have turned either to the northeast, to the lower Raritan, or to the southwest, to the Delaware. There was a deep valley between Trenton and Bakers Basin, but its continuation to the northeast has not been traced

There was a considerable pre-Pensauken valley between Princeton Junction and Penns Neck, and it is probable that at this time the Millstone went southwest from Princeton Junction through Bear Swamp to Port Mercer, and thence southwest to Trenton, though it may have flowed north nearly to Princeton, and then southwest between Penns Neck and Princeton to Port Mercer.

Bear Brook has cut through the Pensauken, and exposes the Cretaceous formations in its channel, thus separating the Pensauken area northeast of this valley from that between it and Assanpink Creek. Above the headwaters of Bear Brook, however, the Pensauken cover is uninterrupted, and is continuous between Hightstown, Allens Station, and Windsor. South by east of Hightstown, small areas of Pensauken have been isolated by the valleys of the Millstone River and its tributaries.

Southeast of Hightstown the Pensauken is limited rather abruptly by the rise of the Cretaceous surface up to levels above that reached by the Pensauken. The prompt rise of the Cretaceous surface here probably corresponds to the scarp farther southwest, through Swedesboro, Woodbury, Haddonfield, Moorestown, Jacksonville and Allentown.

Between Assanpink Creek and Millstone River good exposures of the Pensauken are less common than in areas where the remnants are more isolated. About Dutch Neck, for example, exposures are few. The surface shows a few cobbles and an occasional bowlder, one over 4 feet in diameter. Such data as are available indicate a thickness of less than 20 feet for the formation in this region. Its general relations in this region are shown in Fig. 51 (p. 136).

Near Edinburgh the surface of the Pensauken is affected by undulations like those already noted at a few points to the west, and more conspicuously at a few points to the northeast, as about Fresh Ponds, Dunhams Corners, etc. On the slope to the Assanpink, 1¼ miles northeast of Edinburgh, the surface gives the effect of having low ridges 4 to 8 feet high, much tangled, with undrained depressions between. The open question is whether the ridges are constructional, or whether the substratum, by unequal sinking, moving, etc., has given rise to the undulating surface. One of these curious areas occurs three-fourths of a mile east of north of Edinburgh on the road to Dutch Neck, and similar topography occurs a mile or more west northwest of Locust Corner.

A section of the Pensauken north of Locust Corner in the south bank of the Millstone shows:

4) 3 feet of gravelly loam.
3) 1 foot of coarse stratified sand.
2) ½ foot of gravel.
1) 5 feet of coarse arkose sand, horizontally stratified.

Between Locust Corner and Hightstown exposures are rare. Some cobbles mark the surface, and one angular sandstone bowlder 6 feet long was seen.

In Hightstown the base of the Pensauken has an altitude of between 90 and 100 feet. Northwest of Locust Corner, and again a mile down stream, Pensauken occurs repeatedly at levels below 90 feet. A mile north of the Corner, the base is below 80 feet, and where the wagon road east from Princeton Junction crosses the Millstone, the base is apparently below 70 feet. These elevations show that the pre-Pensauken base declines gradually from the southeast to the northwest, the most abrupt change being at the southeast, where the formation comes against the old headlands.

The character of the Pensauken at Hightstown is essentially the same as at Allentown and Robbinsville,—light-colored arkose sand, with some pebbles scattered through it. It is, or has been, well exposed in the railway cuts in the vicinity. To the eastward, arkose sand occurs even to Etra, a mile and a half southeast of Hightstown, where this phase of the formation grades into the non-arkose phases farther east. In general, the arkose phase is limited at the southeast by the interrupted scarp referred to, a scarp which consisted of headlands separated by valleys 30 to 50 feet deep, and 1 to 3 miles wide.

The vicinity of Hightstown, contrasted with the region farther southwest, as at Allentown, shows one important difference. In the latter place, the Pensauken is arkose in its basal parts only, while near Hightstown it is arkose up to altitudes of 130 feet, or even to 150 feet. The 151-foot hill a mile and a half south of Hightstown, covered with arkose sand, suggests that the Pensauken was built up to this level in this vicinity.

Two miles south of Hightstown, Cretaceous sand appears at the surface at the top of the 153-foot hill and on the slopes below, while a mile to the northwest, the 151-foot hill seems to be

covered with Pensauken gravel to the depth of 20 to 30 feet. A mile or so south of Hightstown, the Pensauken is some 30 feet thick where the surface has an elevation of about 130 feet. These facts show how abruptly the thick body of the formation terminates at the southeast. The pre-Pensauken surface seems to have risen 40 feet at least in half a mile along the east edge of the Pensauken formation. The relations are similar to those at Swedesboro, where the high-level Pensauken drops off from 115 feet, to the low-level phase of the formation, at 70 or 80 feet.

East of Hightstown, a considerable area of Pensauken covers the divide between Millstone River and Rocky Brook. Arkose sand in its various phases is exposed at several points here. The general disposition of the formation between Swedesboro and Hightstown is shown in Fig. 52 (p. 136).

Between the Millstone River and Cranbury Brook.—The broad low divide between these streams is covered continuously with Pensauken from Old Church and Red Tavern on the southeast, nearly to the junction of the streams. The elevation of its base is about 120 feet at Red Tavern, but declines rapidly to 90 feet to the northwest, and then gradually to 70 feet. The surface is characterized by some cobbles and bowlders, among them trap, and in places by the undulatory topography already noted near Edinburgh. Such an area occurs 3½ miles west of Cranbury Station, at the 100-foot level. A trap bowlder 4 to 5 feet in diameter occurs southwest of Cranbury Station, in the valley. This is some 9 miles from the nearest outcrop of trap. These trap bowlders, as well as the others of the region, are doubtless from the Pensauken, and appear most commonly where that formation has been mostly eroded away.

Outlying areas of Pensauken.—Northwest of the Pennsylvania Railroad there are a few outliers of the Pensauken formation. The largest is at Penns Neck, capping the higher part of the tract between Millstone River, Stony Brook, Duck Pond Run, and the railroad. This Penns Neck area appears to have been surrounded by the drainage of the last glacial epoch, making it an island.

There is no indication of a pre-Pensauken valley between Penns Neck and Princeton, lower than 90 feet. Nowhere else in the immediate vicinity is the Pensauken as low as at Princeton Junction. Its base here is about 80 feet above sea level, rarely below 70 feet.

Small remnants of Pensauken occur at about 120 feet southwest of Princeton, and at 100 to 108 feet south of Port Mercer. The Pensauken mantle here is thin and contains much shale. Locally more than half the material is of this sort. Some of the shale-gravel beds suggests, but do not prove, shore action.

Two small patches of Pensauken occur at Lawrenceville, at an elevation of about 120 feet. Larger areas are on the divide at an elevation of about 120 feet a mile and a half east of Lawrenceville, and on the divide at 100 to 110 feet between Port Mercer and Lawrence Station, centering about Clarksville (p. 122).

There are also outlying areas of the formation to the southeast. East of New Sharon, Allens Station, Hightstown and Cranbury Station, there are several small outlying areas of non-arkose gravel, correlated with the Pensauken. They have no distinctive features, as compared with similar areas farther southwest.

Just east of New Sharon, east of Allens Station, just south of Etra (Milford), and at Old Church and Red Tavern, the arkose Pensauken grades into non-arkose, and the Cretaceous base rises rather promptly at the same time. Farther east the gravel remnants regarded as Pensauken are isolated and higher. Southwest of Red Tavern, the arkose phase rarely is higher than 130 feet, but the non-arkose phase rises to 150, 170 and 180 feet, toward the Clarksburg-Perrineville hills. East of these hills, along the Millstone, Pensauken gravels rise even to 200 feet in a belt extending from Bergen Mills on the north, to within a mile of Charleston Springs on the south. These gravels appear to be associated with the Millstone River in origin.

Between Cranbury Brook and Fresh Ponds.—Within the area roughly outlined by the villages of Plainsboro, Cranbury, Union Valley, Jamesburg, Rhode Hall, Fresh Ponds, Deans, and Mon-

mouth Junction, the surface is generally deeply covered with the Pensauken formation. Its surface elevation ranges from about 70 feet at Plainsboro to about 150 feet between Prospect Plains and Jamesburg, and to 170 feet south of Jamesburg, where the non-arkose phase of the formation appears. Between Jamesburg and Englishtown its surface is still higher.

In the vicinity of Jamesburg, its base is at 90 feet, and the formation is 30 to 50 or 60 feet thick. It is well exposed both in road cuts, and in the large excavations along the railway southwest of Jamesburg. Nowhere else is its composition better seen. One of the striking things shown by the excavations along the railway is the presence of a few bowlders up to 3 feet in diameter near the base of the formation. The pebbles and cobbles of crystalline rock are decomposed, but the large bowlders are in some cases solid except for a thin layer on the outside. In the case of bowlders seen in the bottoms of pits, however, a part of the weathered, decomposed exteriors may have sloughed off. Red shale, ranging in size from small bits to slabs a foot or so in diameter, accompanies the bits of crystalline rock. The upper part of the formation appears to have been derived almost wholly from the southeast, and the non-arkose phase of the formation is therefore all that is seen where excavations are shallow.

The section along the railroad exposes some 30 feet of sand and gravel. The uppermost 6 to 10 feet is loamy, and rests with uneven contact on the sand below. The succeeding 20 feet is sand with some gravel, among which bits of granite and red shale occur rarely. Gravel is subordinate to sand in some such ration as 1 : 3. The sand is glauconitic, thin seams highly so. Here and there cementation has taken place at the base of the formation. Among the bowlders, sandstone and quartzite predominate, but one of gabbro 3 feet in diameter was seen in the bottom of the pit. Its source is not known, but no formation from which it could have come is known within the State.

A mile southwest of the railway pit, a well at the 150-foot level, dug to a depth of 70 feet, showed about 50 feet of non-arkose Pensauken, over 10 to 15 feet of arkose material. The arkose part was strikingly white, as at Old Bridge. This is one

of the deepest sections of the Pensauken known. The well was an open one, and the section was seen from top to bottom. It showed conclusively that the foreign (northern) materials of the Pensauken came in first, and that they were followed by the local, southeastern phase, a conclusion confirmed by hundreds of roadside and hillside sections.

The base of the Pensauken rises from 90 feet at Jamesburg to 120 feet just south of Lower Jamesburg, and to 140 feet at Gravel Hill, 4 miles to the southwest. If, therefore, the Pensauken were removed, we should find the Cretaceous surface rising promptly from 90 feet at Jamesburg, to 120 feet just south of Lower Jamesburg, and 20 feet more, four miles farther south. Available data seem to point to the continuation of the 90-foot plain beneath the Pensauken northwest to Princeton and Monmouth Junction, although the Cretaceous surface rises to 100± feet at some points, as 2½ miles southwest of Dayton, along the electric railway.

Southwest of Jamesburg in the vicinity of Prospect Plains and Cranbury, exposures show the same sort of material as about Jamesburg. Toward Cranbury, bowlders are rather common on the surface. Three to four miles west of Jamesburg the undulating, undrained surface already noted elsewhere reappears. The same topography recurs, 1 to 2 miles east of Dayton, and it is still more pronounced west of Rhode Hall, and between Rhode Hall and Fresh Ponds. The relief of the surface here is as much as 20 feet in some places, and is so uneven as to recall morainic topography. Near Fresh Ponds, as the name implies, small ponds are common in the depressions, which are 3 to 8 feet deep and the ponds 2 to 10 rods across. The depressions at Fresh Ponds are, however, not so deep as toward Rhode Hall; but the Cretaceous clay is apparently nearer the surface about Fresh Ponds, and so the depressions hold water better. Many of the original marshes and ponds have been drained, and cuts through the rims of the basins have been seen during the process. They are composed of loose gravel and sand, and the same materials lie below the basins themselves where cuts have been seen. The water in the basins is doubt-

less due to the close proximity of the Raritan clay below, and to the general flatness of the region, which does not favor run-off. Some of the gravel and sand, too, has loam enough with it to make it rather impermeable.

Along the creek east of Fresh Ponds, the base of the Pensauken has an elevation of 100 to 110 feet a mile and a half southeast of Fresh Ponds, and 70 to 80 feet a mile and a half to the northwest, at Lawrence Brook. In the immediate vicinity of Fresh Ponds, the Cretaceous has been seen in various excavations at 90 to 100 feet. About Fresh Ponds, and especially toward Lawrence Brook, bowlders are common at the surface.

The line of old headlands runs northeast of Allens Station, through Red Tavern, Union Valley, and Half Acre, to Lower Jamesburg. Along this line, the most projecting headland is between Allentown and New Sharon, along the south side of Assanpink Creek.

The Pensauken deposits about Jamesburg show that the formation buried and obscured the earlier topography. The 40-foot relief of the Cretaceous surface near Jamesburg was destroyed by the building up of the low lands to the level of the higher. The phenomena here therefore duplicate those at Robbinsville and New Sharon, except that the upbuilding to 150 feet in the latter place is not altogether conclusive, while at Jamesburg it is; and the latter case seems to carry the former with it. If this is correct, the Robbinsville region was once built up to a level harmonious with that at Jamesburg, and the non-arkose upper part has been largely removed, leaving the arkose part below relatively more conspicuous than it once was.

At the southeast, the levels of the Pensauken at Old Church, Red Tavern, Etra, Allens Station, New Sharon and Egg Tavern, are essentially the same, ranging from 145 to 160 feet. The harmony of these levels and the likeness of the material throughout, point to community of origin.

Vicinity of Monmouth Junction.—Between Monmouth Junction and Princeton Junction, the Newark shale is capped by Pensauken gravel, the surface of which is below 120 feet in most places, and its base is as low as 80 feet just west of Monmouth

Junction. Both northwest and northeast of Monmouth Junction its base is at about 100 feet, but toward Dayton, data from wells indicate that its base is at about 90 feet.

It appears therefore that there was a pre-Pensauken plain about 5 miles wide between Jamesburg and Monmouth Junction, the surface of which had little relief. This surface now has an altitude of about 90 feet. This 90-foot lowland appears to have been aggraded some 50 to 60 feet by the deposition of the Pensauken formation.

The area west of Old Bridge.—This area is but a continuation of that to the southwest, nearly cut off from it by the valley of a tributary to Lawrence Brook. The Pensauken formation is well exposed at Old Bridge, Hardenbergh Corners, and a few other points, and its disposition and relations are shown in Fig. 53.

Between Rhode Hall and Old Bridge the base of the Pensauken has an altitude of about 100 feet. At Old Bridge, the uppermost 6 to 10 feet of the formation is gravelly, chiefly quartz and chert, and very compact. The basal member is coarse sand, slightly arkose, and having a coating of white kaolin about the grains in many places. This gives the sand a singularly white appearance. In other places the gravel and sand alternate. The formation is, at a maximum, 50 to 60 feet thick in this area.

At Hardenbergh Corners a fine exposure of the formation is seen in the railway cut. The basal part is coarse, with plenty of crystalline rock and red shale, but the main body of the formation is of fine gravel and sand. A granitic bowlder a foot in diameter was seen here, decayed and soft to the center. Trap bowlders, one of them 3 feet in diameter, are decomposed at the surface only. At this point there is a bed of coarse gravel near the center of the section, with 10 to 15 feet of coarse arkose sand below, and sand with but little gravel above.

Northwest of Dunhams Corners, the Pensauken has been largely removed by Beaver Dam Brook and other tributaries to Lawrence Brook. Along the northwest border of that which remains, its base rises locally to 110 feet (a mile northeast of

Dunhams Corners), but declines northward toward Lawrence Brook. Along the south bank of Beaver Dam Brook, its base declines from about 100 feet west of Dunhams Corners to 60 or 65 feet at Lawrence Brook. In the valley north of Fresh Ponds, its base declines from about 100 feet south of Dunhams Corners to 80 feet.

In the area about Dunhams Corners there are many depressions without outlets, similar to those at various points to the southwest. Some of the depressions contain marshes and ponds, while others are dry. The ponds and marshes are believed to point to the proximity of Cretaceous clay below, the dry basins to a greater thickness of Pensauken, or to underlying Cretaceous sands, as distinct from clay; but these relations can hardly be said to be demonstrated. The surface about Dunhams Corners shows a good deal of coarse stony material.

East of Lawrence Brook and northeast of Milltown, there are some patches of Pensauken, mostly thin, which represent the basal part of the formation.

The Pensauken surface reaches an altitude of 163 feet at Old Bridge, and its base is at 90 to 100 feet. The upland covered by the Pensauken drops off suddenly to the valley of South River by a scarp, facing southeast.

Lawrence Brook and drainage changes.—Lawrence Brook follows approximately the junction of the Newark shale and the Cretaceous system from Deans to Milltown, a position which suggests its adjustment to structure. Its course most of the way is actually a fraction of a mile off the contact, its channel being in Newark shale (locally trap) most of the way. Judging by the disposition of the Pensauken, there was a valley at the contact of the Newark and the Cretaceous beds in pre-Pensauken time, for remnants of the Pensauken formation occur along this line at lower levels than to the northwest and southeast. This holds down the valley to its junction with the Raritan. The pre-Pensauken valley floor declines from an elevation which is now 70 feet at Deans, to 60 feet at Westons Mills; but the valley was narrower at the latter place than at the former.

Between Fresh Ponds and Dayton is the great Pigeon Swamp, which occupies a broad flat valley. Its altitude is about 80 feet, and its borders on the north and south about 20 feet higher. Exposures of the material beneath the swamp are mostly wanting; but some information was afforded by a drainage ditch through the marsh some years since. This ditch reached Cretaceous clay but a few feet below the surface, and at the west end of the swamp Cretaceous beds rise as high as 70 to 80 feet. The Pensauken appears to have been mostly removed from the area where the swamp is. The stream now flowing through it is small, and apparently inadequate for the work of erosion which seems to have been accomplished. The swamp is quite unlike the valleys of other tributaries to Lawrence Brook, for the others seem capable of having made the valleys they occupy.

Southeast of Pigeon Swamp there is a broad depression, a mile southwest of Rhode Hall, at about 90 feet. It is three-fourths of a mile wide, and opens out into the valley of Manalapan Creek to the southeast. It seems possible that Manalapan Creek flowed through this gap in post-Pensauken time, going on northwest through what is now Pigeon Swamp, to Lawrence Brook. The valley of South River, between Jamesburg and Old Bridge, is probably following a course assumed in post-Pensauken time.

The early post-Pensauken drainage may have been somewhat as follows: 1) A stream flowing northwest from Wickatunk to Old Bridge, joining the Raritan in the vicinity of Sayreville; 2) Manalapan Creek, flowing northwest from Manalapan to Jamesburg, and thence to Lawrence Brook at Deans Station; 3) Lawrence Brook, flowing to the Raritan in a valley in the Pensauken formation, overlying Newark shale. The first of these three streams excavated its valley faster than the last. After it had been sunk through the Pensauken into the Raritan formation, it had great advantage over Lawrence Brook after the latter reached the Newark shale. It is conjectured that a tributary to the Old Bridge-Sayreville stream developed southwest from Old Bridge until it tapped Manalapan Creek in the vicinity of Jamesburg and led it off to its main, now South River. This diversion of Manalapan Creek left the gap southwest of Rhode Hall un-

occupied by a stream, and the valley of the beheaded part of the former Manalapan Creek became swampy (Pigeon Swamp), as a result of the sluggish drainage which resulted from the lessened flow.

Deposits between Lawrence Brook and the Raritan River.— North of Lawrence Brook the Pensauken formation occurs most of the way from Deans to New Brunswick, the Pennsylvania Railroad marking, in a general way, its northwestern limit. Its surface here has an elevation of from about 100 feet to 125 feet. At New Brunswick its base has an elevation of about 110 to 120 feet, but it declines to about 70 feet at Westons Mills.

The formation here is somewhat drift-like in composition, containing much coarse material of northern origin. It lacks evident stratification in places, especially in the railway cuts between New Brunswick and Milltown, at 110 to 120 feet. The material here is very unlike that at Milltown and southeast of Lawrence Brook, and has somewhat the appearance of glacial drift. In many places the gravel is associated with a good deal of clay from the Newark shale, emphasizing its drift-like aspect. The hypothesis has been entertained that the ice at some time reached this latitude, but proof of its truth is wanting.

South and west of New Brunswick (Voorhees, Clyde, and Middlebush) are scattered bits, but not considerable beds of Pensauken material. Large tracts here which are at levels appropriate for the formation are without it, and the reason for its absence is not altogether clear. (1) Was the New Brunswick region built up to 160 feet, the Old Bridge level, and since lowered by erosion, or (2) was this region too high *in Pensauken time,* for the deposition of that formation? In either case there has been much erosion since. A third alternative is that the Old Bridge-Amboy region has been raised a little, relative to the New Brunswick region, since the Pensauken epoch. Which, if any, of these conjectures is correct, is undetermined.

One and one-half miles west of Franklin Park, and 2½ miles east of Griggstown, the 150-foot hill has a cap of 10 feet or so of gravel. A mile north of west of this, the 140-foot hill has a gravel cap very like the gravel and sand about New Bruns-

wick and Metuchen, though containing less shale. These hill cappings are probably Pensauken, though not of the normal phase. They suggest the first of the hypotheses noted above.

A mile and a quarter northwest of Franklin Park there is a 130-foot area mantled by gravel, and half a mile farther northwest there is another area of gravel at the same (maximum) elevation. In all these places the gravel is lower on the north slopes of the elevations than on the south. This may be the result of displacement, though this is not clear.

West of the Millstone River.—West of the Millstone River, and a mile northwest of Griggstown, there is an area of gravel and loam at about 125 feet. The gravel here differs from that to the east, in that it has more small quartz pebbles—rather of the Beacon Hill type. East of the river, sandstones, quartzite, shale, etc., are more prominent. South of Blawenburg, at 120 to 130 feet, there are remnants of gravel like those about Griggstown and Franklin Park.

The above remnants at 120 to 150 feet are perhaps all Pensauken, and indicate a general mantling at this level. So far as this region is concerned, there might be doubt as to the age of the material; but if the preceding interpretations are correct, Pensauken occurs at 160 to 170 at Jamesburg, 165 at Old Bridge, 150 at Rhode Hall, and at 160 feet north of Somerville. In view of this distribution, it is not unreasonable to refer all these remnants to the Pensauken. An alternative view is that the high remnants noted are remnants of the Bridgeton formation, the base of which has an elevation of 130 to 140 feet near Glassboro, and 90 feet at Bridgeton. If, however, this dip were carried northward, it would carry the base of the formation far above the level of these gravels from Franklin Park to Blawenburg. Another alternative is that the gravels referred to are of various ages, and not referable to any one distinct stage of deposition.

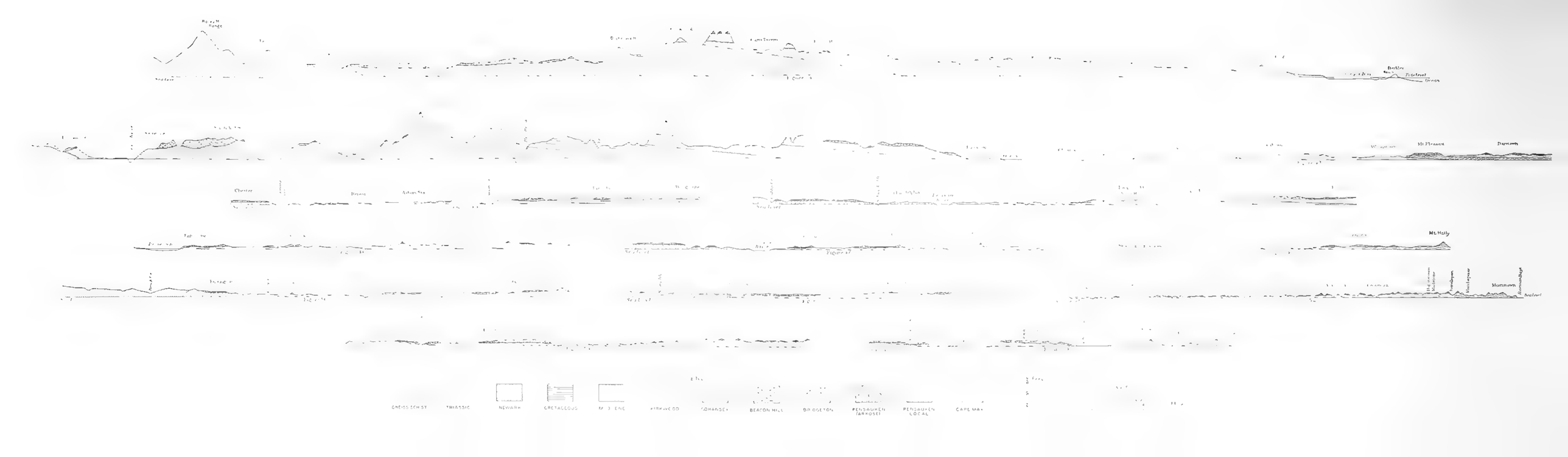
One of the most remarkable areas of the Pensauken formation occurs at Kingston on the east side of the Millstone River just south of the gap in the Rocky Hill range. In coarseness, proportion of crystalline material, and decay of bowlders, this deposit is unique. Many bowlders 1 to 1½ feet in diameter are

decayed to the very center; while others have a 2- or 3-inch core which is firm. A large part of the thick deposit is of large cobbles, yet there is matrix enough so that the material stands with vertical faces year after year. The gravel fills a river gorge from an elevation of 50 or 55 feet up to 100 feet, and then spreads out on the higher land to the east of the gorge. The gravel came from the north, and apparently it must have been brought in by a stream which flowed south. Down to this point the river must have been swift to have brought in the coarse material, which becomes finer and finer with increasing distance from the gorge. The southward connection of the valley of the stream which deposited the Kingston gravel is not known.

Pensauken gravel and sand cover much of the area between Monmouth Junction and Kingston northwest of the Pennsylvania Railroad. The base of the formation here has an elevation of 80 to 100 feet, being highest at the west.

North of the Raritan.—The Pensauken is well developed in a triangular area roughly outlined by lines drawn between Metuchen, Bonhamtown and Piscataway. It covers the contact of the Newark and Raritan, overlapping it in both directions. Mill Brook and the lower end of Piscataway Creek have cut through the Pensauken and have their channels in the Newark shale. When Pensauken deposition took place here, remnants only of the Raritan formation remained, and the Pensauken buried Newark and Raritan alike. The general disposition and relations of the formation between Metuchen and South Amboy are shown in Fig. 54.

The surface of the Pensauken now slopes from a maximum elevation of 134 feet near Metuchen, to 100 feet or less at Bonhamtown; in other words, it has a gentle slope to the southeast. The base of the formation is lowest along a line southwest from Bonhamtown, and higher to the southeast and northwest of this line. The belt where the base is lowest doubtless marks the site of a pre-Pensauken valley. Mill Brook follows this old valley more than a mile southwest of Bonhamtown, and there it turns south and follows a post-Pensauken valley to the Raritan.


Mt Holly
Mammoth
CRETACEOUS
KIRKWOOD
COHANSEY
BEACON HILL
BRIDGETON
PENSAUKEN (ARNOSE)
PENSAUKEN LOCAL
CAPE MAY

Along the old valley, the Pensauken base has an elevation of 60 feet or so, and on either side it is about 20 feet higher. The stream in this old valley flowed to the southwest, joining the Raritan valley somewhere near the lower end of the present Piscataway Creek.

Between Highland Park and Metuchen, the ragged edge of the Pensauken shows much coarse gravel on the shale, left as the edge of the formation was removed. The material of the Pensauken is coarser west of Mill Brook than is its wont, and has such features as to raise the question whether it is not the remnant of a drift sheet older than that which made the well-developed moraine from Metuchen to Perth Amboy.

A quarter of a mile southeast of Piscataway, at the roadside, the Pensauken section is as follows:

3) 3 feet gravelly sand with seams of red loam (doubtfully Pensauken?)
2) 20 feet of sand with seams of gravel. The pebbles are largely quartz, but there are many red shale bits and a few granitic pebbles.
1) 7 feet coarse white arkose sand with a little gravel.

At Bonhamtown, there is a large gravel pit exposing the formation well. The section is not unlike that at Piscataway, and is somewhat like that at Jamesburg, where 30 to 50 feet of sand and gravel, chiefly from the southeast, overlie 2 to 10 feet of arkose gravel and sand, the two types of material being distinct. At Bonhamtown, however, the arkose and non-arkose types are more or less intermingled, or interbedded, or at least are not sharply separated. As seen in section here, the material at a given level is not arkose, while a short distance away material at the same level is arkose. In no part of the section is the material so free from sand of Cretaceous origin as is the basal part at Jamesburg. It is clear that two different sources contributed to the deposit at Bonhamtown, and that now one and now the other made the larger contribution, while at other times the two were about equal. Stratification is more distinct than at Jamesburg. The sand and the gravel are commonly in nearly horizontal, lens-like beds, a few inches thick. The gravel is

rather fine, most of the pebbles being less than an inch in diameter, though cobbles occur, and rarely a bowlder. Among the pebbles are bits of red shale and granite. Most of the sand is yellow and brownish in color, but some of it is white; some of it is arkose.

West of Bonhamtown, on Mill Brook, exposures have been seen which are especially till-like,—so much so as to lead one instinctively to look for striated bowlders, but none have been found. Locally red shale constitutes 75 per cent. of the whole.

Another remnant of Pensauken occurs at Sand Hills, east of Bonhamtown, and still other cuts and pits show it to be present beneath the glacial drift near Woodbridge and farther south. Thus a mile or so southwest of the Woodbridge depot, in the 140-foot hill, 40 feet of Pensauken sand has been seen in section. The sand is of the arkose type, yellowish to white in color, somewhat like that at Old Bridge. There is little fine gravel here. The material differs from that at Bonhamtown in being more arkose and less gravelly.

At Metuchen, the Pensauken has been seen well exposed in railway cuts northeast of the depot (Perth Amboy line). Quartz pebbles make up much of the gravel; but quartzite and sandstone are present both as gravel and in larger pieces. Pieces of red shale are common, as are small bits of granite, thoroughly decomposed. In some places the composition of the material suggests glacial drift, but it is in striking contrast with the last glacial drift a few rods to the north.

A mile northeast of Metuchen depot, and three-fourths of a mile east of south of Menlo Park, Pensauken with a distinctly till-like structure has been seen beneath glacial drift; but glacial stones were not found in it.

In the area north of the Raritan and east of the Pennsylvania Railroad, the Pensauken has two somewhat distinct phases: the one, arkose sand; the other gravel in which red shale and granite are prominent. Locally there is much clay with the gravel and bowlders, and the structure is somewhat till-like. Though the two phases have not been seen in section, general relations suggest that the sand was deposited first, and the coarser material later; but that in time of origin, the two were not far apart.

Between South River and Cheesequake Creek.—The Pensauken is well developed about South Amboy and Ernston. Its surface reaches an altitude of 170 feet near Ernston, though it rises above 150 feet in but few places. Its base has an altitude of about 90 to 100 feet in most places, thus giving it a probable maximum thickness of about 70 feet.

The section shown along the Pennsylvania Railroad a mile or so southwest of the depot is representative:

5) 2 feet moulding sand or loam, locally almost a clay loam.
4) 6 feet coarse gravelly sand.
3) 15 feet yellow arkose sand free from gravel.
2) 6 feet arkose sand, brownish in color, with some pebbles.
1) 4 feet of coarse gravel, including occasional bowlders; granitic and shale pebbles common.
Cretaceous.

Sections showing material like parts of the above are common. At the crossing of Bordentown Avenue and the Raritan River Railroad, several large bowlders (3 feet and less in diameter) have been seen at the base of the formation.

South and west of South Amboy there are numerous exposures at high levels. In general the gravelly material is almost wholly quartz. A three-fold division of the formation prevails, namely

3) Quartz-chert gravel, 2 to 15 feet.
2) Arkose sand, 10 to 40 feet.
1) Coarse gravel, with cobbles and even bowlders, bits of shale and granite, ½ foot to 4 feet.

About Ernston and toward Sayreville the material and its relations are the same as at South Amboy.

One and three-fourths miles southwest of Ernston, along the railway near the old Poor Farm, the base of the Pensauken runs down to 20–30 feet, and possibly lower. A quarter of a mile or so farther northeast, the base of the formation is above 90 feet. Again, a little more than half a mile west of Morgan Station, Pensauken is seen at 20 feet. These low-lying remnants do not appear to be displaced, though possibly they are. If not, they mark the position of rather deep pre-Pensauken valleys, like those east of Camden.

The Pensauken about South Amboy and Ernston represents the northwest phase of the formation, as distinct from the southeast phase, a distinction which has held across the State from Delaware Bay to this point. The distinction is as sharp here as to the southwest. The arkose phase of the Pensauken is limited at the south by the valley of Cheesequake Creek.

OUTLYING AREAS OF PENSAUKEN, EAST OF SOUTH RIVER.

Northwest of Englishtown.—There is a cap of Pensauken gravel, of non-arkose type, on Gravel Hill west of Manalapan Creek, a mile and more southeast of Hoffmans Station. This connects with the arkose Pensauken south of Jamesburg. Similar gravel covers the divide a mile or so east of Manalapan Creek between Englishtown and Jamestown. The material in the two places is essentiallly alike, and occurs at similar elevations, and the two areas probably were connected originally. They reach a maximum altitude of 187 feet, and the altitude of their bases ranges from 140± feet at the south, to 80 feet at the northwest. They seem to correlate with the main body of the formation to the northwest. The material here is non-arkose, like the upper part of the formation in the Jamesburg railway cut. These areas have their chief significance in connection with remnants of gravel, probably of Pensauken age, about the headwaters of the Matchaponix drainage system, east of Englishtown and north of Freehold.

Southeast and east of Englishtown.—East of South River and Matchaponix Brook there is relatively little material which can be correlated with the Pensauken with certainty. Southeast of Englishtown there are patches of gravel—some small, some large—near Manalapan Creek, above Blacks Mills, and about the headwaters of the creeks which unite to form Matchaponix Brook, as on Monmouth battleground, in the vicinity of Lafayette Mills, Gordons Corners, Union Hill, and elsewhere; or, in general, in an area extending from Robertsville (2 miles west of Wickatunk) on the north, to Blacks Mills (4 miles west of Freehold) on the south. These gravels are below the level

appropriate for the Bridgeton formation, and appear to be stream deposits, left in the general degradation of the region from a higher level. They decline to the west and northwest, in harmony with the present drainage, whereas the Bridgeton of the region is not definitely related to the present drainage, and its base declines to the southeast. Some of these gravels seem to be correlated clearly with the Pensauken to the northwest, while others may be somewhat younger. Indeed, it does not seem practicable to determine their age with certainty. On the whole, it seems reasonable to regard them as contemporaneous, at least in a general way, with the Pensauken at Jamesburg, and to have resulted from the effects of the deposition about Jamesburg, on the drainage of the area here under consideration.

On the south side of Wemrock Brook, between Englishtown and Freehold, several patches of gravel occur at elevations ranging from 160 feet at the east to 120 feet at the west, on hilltops and divides. The gravel caps are not known to be thick, but the depth of material is rarely exposed. All these gravel remnants lie on a surface some 50 feet below the divide between the Matchaponix and Manasquan systems, on what may be regarded as remnants of a surface which once sloped gently northwestward.

The original Beacon Hill level for this region should have been 350 to 400 feet, so that the Freehold region has been degraded some 200 feet since that time. The gravels along Wemrock Brook were probably derived from the Beacon Hill formation, and left along old stream courses. They are too low for the Bridgeton, and since they agree in level with the Pensauken not far away, they are referred to that formation.

On the divide between Wemrock Brook and the south branch of Tepeheptus Brook, there are other patches of gravel similarly situated. One patch occupies a part of the Monmouth Battleground, where 12 to 15 feet of glauconitic sand and loam overlie 1 to 3 feet of gravel, concealing it in most places. Farther west there are isolated hills at slightly lower levels, capped with gravel. The altitude of these patches ranges from 180 feet near Freehold, to 120 feet in the vicinity of Taylors Mill, a mile east of Englishtown.

Between the branches of Tepeheptus Brook there are other patches of gravel similarly situated, at elevations ranging from 170+ to 110 feet, the higher elevations being to the east, 2 miles or so west of Marlboro. These hills, taken with other patches at similar elevations in the vicinity, seem to point to a widespread accumulation of gravel at a level which is now about 180 feet above the sea in the vicinity of Freehold. It is thought that the gravels here referred to accumulated in the valleys at about this level. The sites of the valleys have been changed since, and their former sites have, in some places, become divides. The base of the gravel in some of these patches about the headwaters of Tepeheptus Brook is very irregular, in a small way, and the irregularities are not unlike those developed in the channels of existing streams.

Between Tepeheptus Brook and Milford Brook and about the headwaters of the latter, the phenomena just described are repeated, the gravels being at similar levels, 170± feet. The patches show a tendency to elongation on the divides parallel to the streams. The higher tracts (170 to 180 feet) covered with gravel adjoin still higher lands (200± feet) on the east, east of north of Freehold. These high lands carry some gravels which seem to be older than the remnants at lower levels to the west, though this may be questioned. The high gravels hereabout are cemented to a considerable extent, and so have the appearance of greater age.

Are the gravels between Englishtown and Freehold the equivalent of those northwest of Englishtown? To this question no positive answer can be given. The former have the appearance of having been accumulated in stream valleys, for they vary from valley to valley, in keeping with the terranes affected by the drainage system. West of Englishtown, such a relation is not evident.

If these gravels east of Englishtown were once part of the main body of Pensauken to the west, they would seem to call for the building up of the area between Englishtown and Freehold to 180± feet by Pensauken deposits. In this case the remnants we now find at 120 feet are basal remnants of a bed once 60 to

80 feet deep. This hypothesis does not seem to be strongly supported by known facts.

The composition of the gravels northeast of Englishtown suggests (Knapp) that they were deposited after the Beacon Hill (and after the Bridgeton if the latter ever was here) was largely removed, when the Cretaceous beds contributed more to the surface gravels than they did when the gravels northwest of Englishtown were deposited. This would suggest that the gravels northeast of Englishtown are somewhat younger than those to the northwest.

Knapp suggests that a plain sloping from 180 feet at Freehold to 140 feet at Englishtown and 120 feet at Jamesburg, was covered with Pensauken gravel, slightly to the southeast, and heavily to the northwest. In later erosion, the higher southeast region suffered most, and the gravels and most super-Cretaceous beds were removed, while to the northwest the surface beds were not so fully worn away. Later deposits northeast of Englishtown contained more Cretaceous material than the beds farther northwest, because the older gravels to the northwest were never removed so completely. This would make the gravels between Freehold and Englishtown somewhat younger than those of Gravel Hill. Analogous relations are found in the vicinity of New Sharon and elsewhere.

Northeast of Englishtown.—The possible Pensauken gravels here range from 110 feet (Clayton's Hill) near Englishtown, to nearly 200 feet near Wickatunk. To the west, the gravel caps small hills, and is 6 to 8 feet thick. It is, on the whole, poorly assorted, but with loam enough to make it fairly compact. Its base is irregular. In the larger patches, it runs down the spurs of the hills to levels below those of its base in the hilltops. In some of it, good sized cobbles occur, as at Gordons Corners, but they are not plentiful. The matrix of the gravel contains some greensand (now brown). In a pit at about 170 feet, 3 miles west-northwest of Marlboro, the composition of the gravel is as follows: 5 per cent. chert, 10 per cent. ironstone, and 80 per cent. quartz, about 3 per cent. being of cobble size. The sand with the gravel is about half glauconite. Other

areas west and southwest of Wickatunk repeat these phenomena. with variations. What appears to be wind-blown sand, in many places glauconitic, covers the gravel in places. Correlations are uncertain.

A few areas of gravel at higher levels (190 to 200 feet) about Wickatunk, Knapp regards as perhaps Bridgeton, but the reasons for separating them from the Pensauken do not seem to be altogether convincing.

Disregarding some doubtful areas, there is a decline in the Pensauken surface from 170 feet 3 miles west of Wickatunk, to 120 feet near Englishtown, a decline in the direction of present drainage. The base of the gravels is marked by numerous irregularities of a trifling sort.

The character of these gravels indicates their local origin, but it varies much from point to point, quartz and ironstone alternating with each other as chief constituents. In general, the gravels at the lower levels are the better stratified.

Green surface loam abounds about the headwaters of Matchaponix Brook, from Freehold to Wickatunk. It is so persistent that some general explanation seems called for. In depth it ranges from 5 feet to 20 feet, and its constitution suggests the Red Bank formation as its source. Its distribution is consistent with an eolian rather than a fluviatile origin.

Between Pine Brook and Barckleys Brook there is a series of gravel capped hills, declining from near 200 feet at the northeast (Robertsville) to 120 feet or so near Mounts Mills. In composition, the gravel ranges from quartz 2 : ironstone 1, to ironstone 3 : quartz 1. The gravel is, in part, well stratified, is mostly rather fine, and is most plentiful below the top of the formation.

The divide west of Wickatunk, extending to Robertsville and thence northwest between Deep Run and Barckleys Brook, separates two sets of gravel deposits, the one about Englishtown and northeast, and the other about Browntown and Matawan. The southern of these two regions includes the headwaters of Matchaponix Brook. In pre-Pensauken time this area seems to have had a surface sloping from the northeast, east, and southeast,

toward Englishtown. The area was somewhat amphitheatral in shape, with its rim at about 170 feet, and its low point at Englishtown, at about 110 feet. The material here which is regarded as possibly Pensauken contains notably more that was derived from the Cretaceous, than does the gravel at Gravel Hill and on the divide northwest of Englishtown. If early post-Pensauken drainage from the Matawan-Freehold region went to New Brunswick, and thence by way of Bound Brook through Kingston to Trenton, the course was very roundabout. If the present course of the Raritan to the ocean was developed after the gravel west of Englishtown was deposited, the change would have greatly facilitated erosion in the Englishtown region.

North of Deep Run.—The gravel remnants in this region which seem most confidently correlated with the Pensauken are those at 120 to 150 feet in the vicinity of Morristown, Morganville, and Browntown. The Cretaceous surface beneath the Pensauken at South Amboy and Old Bridge and Jamesburg, it will be remembered, has an elevation of about 90 feet. The gravels regarded as probably Pensauken about Morganville have an elevation of about 150, suggesting a Cretaceous surface sloping from 150 feet at Morganville to 90 feet at Old Bridge, just before the deposition of the Pensauken. No stream such as Matawan Creek or Cheesequake Creek seems to have been located along the strike of the Cretaceous beds at that time, and the creeks mentioned above seem to be of post-Pensauken origin.

Two miles northwest of Matawan, there is an elongate divide (Morristown-Jacksonville or Cheesequake) at an elevation of 130 to 150 feet, which has a gravel cap not less than 12 feet thick. Stratification is distinct, but assortment poor. Many pebbles stand on end, indicating rough or swift waters. Quartz and ironstone are both abundant, the latter partly in large slabs. The sand, which is largely beneath the gravel, has much glauconite. The gravel is very like the uppermost member of the Pensauken at South Amboy.

About the headwaters of Tennents Brook, especially on the divide between Browntown and Morganville, there are numerous hilltop gravel caps which are perhaps to be correlated with the

Pensauken. They are at altitudes ranging from 120 to 150 feet, and the depth of the gravel is known to range up to 8 feet. Higher hills east of Browntown, at 200± feet, do not have gravel caps, though surface pebbles suggest the former presence of a higher stratum carrying gravel. The gravel caps southeast of Browntown are all of southeastern material.

The gravel is similar, in all essential respects, to that between Englishtown and Freehold. It is not certain that it ever covered all the area within which the present remnants exist. As in most of the gravel caps of this region, the base is uneven. The floors of the pits, after the gravel has been removed, resemble the channels of small streams in some cases, the pockets of gravel being in more or less sinuous lines, comparable to scour holes in the beds of streams. In one of the gravel pits southwest of Morganville, the gravel after removal, was seen to have occupied a trough (channel) in what is now the crest of the elevation on which the gravel rests.

Locally, the ironstone makes up 95 per cent. of the gravel, though in most places it is subordinate to the quartz. Large pieces of both materials are of local occurrence. Two miles southwest of Morganville, the matrix of the gravel contains much marl, clearly from the Navesink marl.

Some of the beds of gravel here suggest displacement down slope. The original level of deposition seems to have been 130 to 150 feet. One fact leading to this inference is the greater depth of the gravel on the hilltops at these levels.

The surface on which the Pensauken was deposited northwest of Matawan, sloped toward the northwest, as if developed by drainage in that direction. Raritan Bay probably did not exist when this plain was developed. The valleys of Matawan and Cheesequake creeks have developed since Raritan Bay came into existence. They are clearly young creeks. They will, if not interfered with, send their heads farther and farther back into the country to the southwest.

The 150-foot plain, remnants of which appear west of Matawan, and thence to Freehold and Englishtown, would seem to be too high (now) for development at this level, with the drain-

age as it now is. But it is perhaps not too high if the drainage which developed it followed a sufficiently roundabout route when the plain was making. If, for example, the drainage of the Matchaponix went to Trenton by way of Bound Brook (city), and up the present Millstone, the headwaters of the Matchaponix, Deep Run, etc., might have developed a plain at a high level, possibly 150 feet. Furthermore, if the stream which these creeks joined crossed Rocky Hill 100 feet or less above sea level, this would have been the base controlling all levels above. A base at 70 feet at Kingston, would mean a fall of 80 feet from Englishtown, by way of Bound Brook, to Kingston, and this is probably not too high for the development of a plain at 150 feet at the former place.

OUTLYING AREAS EAST OF MATAWAN.

General Statement.—Between Matawan on the west and Atlantic Highlands on the east, there are numerous patches of gravel at levels which are rather low (50 feet to 90 feet) for Pensauken. Similar gravels occur south of Matawan and west of Cliffwood. These gravels are doubtless the counterpart of similar deposits south of the divide between Morganville and Middletown, but their correlation with the Pensauken is doubtful. They are perhaps the equivalent of the surface accumulations between Freehold and Englishtown, being somewhat younger than the Pensauken. Mr. Knapp is disposed to recognize a stage of deposition between the Pensauken and the Cape May, calling it *Walnford,* and would group the surface deposits between Matawan and Atlantic Highlands above the level of the Cape May formation under this name. Irrespective of the name, and of the probable existence of a stage of deposition between the Pensauken and the Cape May distinct enough to be separately recognized, it is probably true that the gravels mentioned above are intermediate in age between the Pensauken and the Cape May formations. Gravels a mile southwest of Cliffwood belong to the same category.

Knapp thinks the equivalent of the Jobstown flat can be traced, with interruptions, to Englishtown, and that its equivalent at

Matawan has an altitude of about 70 feet. The gravels, etc., on this ill-defined plain he would regard as post Pensauken, and probably pre-Cape May. If this is the case, there is no gravel equivalent to Pensauken in the area east of Matawan. The topography of this region is youthful, and the streams are eroding vigorously. Any Pensauken that once existed here may have been removed.

Topographic history.—It seems permissible to entertain the view that the major divide of the region, even in Pensauken time, extended from Matawan northeast to Long Island, and that from this divide there was a gentle slope toward Amboy. The absence of streams along the strike of the Cretaceous, in pre-Pensauken time, in such relations as those of Matawan and Cheesequake creeks, seems to imply the absence of a master stream along the lower course of the Raritan. This suggests the flow of that stream from Bound Brook via Kingston to the Delaware at Trenton.

If the lower Raritan below Bound Brook assumed its present course after the Pensauken epoch, the drainage relations in the direction of Raritan Bay were profundly altered when the present course was established, while those to the southeast were not. This might have made great differences in the deposits of post-Pensauken time, on the two sides of the divide.

South of Matawan are hills 380 to 400 feet high with caps of Beacon Hill gravel, overlying Cohansey sand. The Cohansey and Beacon Hill formations once extended much farther north and northwest, probably reaching the present highlands (at an elevation of more than 400 feet) at the north. The Beacon Hill gravels may be taken as representing the starting point in the topographic development of the region.

Post-Beacon Hill drainage probably involved the flow of the antecedent of the Hudson across New Jersey. Adjacent to it, over a wide belt, the Beacon Hill and older beds down to the Cretaceous were removed, and a broad lowland was developed. To the southeast of the lowland, lay the main divide, perhaps from Long Island to Wickatunk, thence to Freehold, Clarksburg, Cream Ridge, Mt. Holly, Berlin, Glassboro, and Shiloh.

Adjacent to the plain of degradation developed by the main stream, there were minor plains along minor streams. The Woodstown Plain and its correlatives Knapp thinks traceable, by means of the parts remaining, nearly to Matawan. From this point east, the topography was developed by drainage to the northeast; all the rest of the way to Delaware Bay, the larger features of the topography near the broad valley between Amboy and Bordentown and Salem were developed by drainage which flowed to the northwest when the Pensauken gravels were deposited.

If major streams are made the basis of comparison, the broad plain from Amboy to Salem was controlled by a southwest flowing stream, while a narrow belt, northeast of a line from Wickatunk to Browntown, was controlled by drainage to the east.

After the main plain of degradation was developed, the drainage was changed, and Hudson River and Raritan River reached the ocean where Raritan Bay is now. Whether this change took place before or after the close of the Pensauken epoch is not now clear. After this change, present drainage was established, and the continuation of the old main divide east of Wickatunk was destroyed.

Description of deposits.—Within this area there is a series of gravel patches which Knapp regarded as Walnford (p. 147), which are of uncertain correlation. Several of them are elongate north and south, roughly parallel to the present streams. The westernmost is just south of Matawan, at an elevation ranging from 130 feet at the south to 60 feet at the north. At the south end only is the gravel well exposed. It contains much ironstone, some of which is in slabs a foot in diameter. Some of it is from the Red Bank formation of the Cretaceous system, and some from younger gravelly formations. The gravel and sand have a maximum thickness of at least 20 feet, are poorly stratified and poorly assorted, so far as the structure has been seen. With the gravel is more or less sand and marl from local terranes just to the south, exposed in the slopes north of Beacon Hill. Exposures in the west part of this area show the Cretaceous surface to be very irregular, and the gravel fills small gully-like

channels, not unlike those on the slopes of the hills to the south. After the gravels were deposited, drainage abandoned its old channels, and took new ones more easily eroded.

A little farther south there are small isolated hills at 140 feet and higher, capped with gravel which may well be regarded as Pensauken, and correlated with the gravel caps about Morganville, Morristown, Hightstown, etc.

Other minor patches of gravel between Matawan and Atlantic Highlands and below the level which seems appropriate for the Pensauken, need not be separately mentioned. There is one considerable area of such gravel between Hazlet and Matawan. It has an altitude of 140 feet at the south, and declines to 60 feet in a mile and a half. The material is similar to that farther west. South of Hazlet is another patch of similar material, with a good exposure a mile south of the station. It runs up to 170 feet at the south. Here again, the gravel fills an old valley. The gravel has a maximum depth of about 20 feet. The material is like that south of Matawan, except that there is more coarse gravel here, and fewer ironstone slabs. The constitution of the material points to the hills to the south as its source. The section is as follows:

3) 2 feet clay loam, generally with U-shaped pockets running down into 2), 2 feet more.
2) 6 feet coarse gravel, with matrix enough to make it compact. About 5 per cent. of the sand is glauconite. Ironstone fragments make up more than half the gravel. They are but little worn and some of them are slabs a foot or more across.
1) 4 to 6 feet of gravel and sand, less coarse, less compact than 2), with more quartz.

Southeast of Hazlet there is another patch of similar gravel, well exposed in pits. Quartz and ironstone are in the proportions of about 1 : 4. There are cobbles of quartz, and pieces of ironstone several inches across. This patch, like the one to the west, seems to be the site of an old shallow valley. In this case, a later valley cuts diagonally across the course of the stream which deposited the gravel.

West of Waycake Creek, a mile and a half south of east of Hazlet, there is a patch of gravel 10 to 12 feet thick at an altitude

of 110 to 70 feet. Ironstone, the major constituent, is partly from the Beacon Hill formation, and partly from the Cretaceous. The gravel is poorly cemented and poorly stratified. Knapp thinks this an accumulation of general fan type, at the bases of the hills to the south. The material is coarser at the south, and finer at the north, away from the hills. Along the west side of the creek are many patches of gravel ranging in altitude from 120 feet up stream, to 60 feet farther down. These gravels and sands are derived chiefly from Cretaceous beds up stream. They have a thickness of 20 feet in places, and are disposed in rude terraces. They represent former valley aggradation from an altitude of 120 feet down to 70± feet.

Similar deposits occur east of Waycake Creek, in positions corresponding to those on the west. Little or no gravel is exposed, and the material does not constitute terraces, as on the west side of the stream. There are other similar gravels about New Monmouth, at levels of 60 feet and less.

There is a considerable bed of gravel at Hopping at an altitude of 60 feet, with its base at 40 feet. The gravel thickens northward and has a maximum depth of about 20 feet. It is well stratified and assorted. It is not clear that the material about Hopping is separable from the Cape May formation, but it does not form a terrace and nearly bare Cretaceous lies between it and the coast. Its topographic position seems to make it older than the Cape May, and younger than Pensauken.

There is much doubt as to the correlation of all these patches of gravel and sand (Walnford of Knapp) as well as of isolated patches which Knapp has classed as probably Cape May between Keyport and Red Bank, and in the area to the north of this line.

Between Hazlet and Keansburg, but nearer the latter place, are several gravel-capped hills at an elevation of about 85 to 100 feet. Exposures of 7 feet of gravel are seen, with base sloping northward. These patches are probably to be regarded as Pensauken. On some of the hills the material is very coarse, including bowlders a foot in diameter. Miocene (Kirkwood) quartzite is recognized among them. Some of the ironstone, too, is in large pieces, and little rounded.

A mile northwest of New Monmouth are two other isolated hills having heights of 83 feet and 75 feet, with gravel caps similar to those farther west. These hilltop beds seem, from their topographic position, to be distinctly older than the gravels along Waycake Creek.

All those gravels regarded by Knapp as "Walnford" appear to have accumulated at the base of the marl highlands which extend from Morganville to Middletown. At the south the gravels start at 100 to 140 feet, and run down to 80 or less to the north. Many of them appear to be fan accumulations. The isolated hilltop gravels, while fairly harmonious in altitude, seem topographically distinct from the larger areas of gravel nearer the streams, and older. The disposition of the younger gravels suggests that the region was lower than now when they accumulated, else they would have gone down stream farther. If they did go down farther, their lower parts were destroyed later, or buried by the Cape May formation.

The Cape May terrace at 40± feet at Atlantic Highlands, Cliffwood, and at other points to the northwest of Cliffwood, indicate a stand of land lower than the present. With this lower stand, there would have been deposition up stream. Are the "Walnford" deposits just referred to equivalents of the Cape May terraces about the coast? Their position might make this seem plausible, but their topography, and the erosion they have suffered, indicate their greater age.

In the Navesink Highlands, Cohansey sand is present, and possibly Beacon Hill gravel. The base of the Cohansey sand has an altitude of about 180 feet. Between 180 feet and 50 feet the Cretaceous has little cover, except for wash and talus.

THE PENSAUKEN FORMATION ON THE ATLANTIC SLOPE.

In the basin of Swimming River.—The basin of Swimming River is surrounded by high lands, which rise above the level of Pensauken deposits on all sides but the east; but within the basin there are, at levels somewhat below the surrounding divides, various hills capped with gravels which are too high for the Cape

May formation, and some of them may be of Pensauken age. These patches of hilltop gravel are somewhat widely distributed.

North of Nut Swamp Brook, there is a series of these patches on the divide at altitudes of 90 to 140 feet. The lower patches occur down stream, the higher up stream, but all are within 2 miles of one another. The gravel caps are thin. Their range in altitude is great, and possibly all are not contemporaneous.

One to three miles west of Red Bank and south of Nut Swamp Branch there is a similar series of gravel-capped hills at elevations of 80 to 112 feet. The gravel caps are several feet (10 to 15 feet) thick, and the gravel is of quartz and ironstone, with loam enough to cause the material to pack well. Cobbles of Miocene quartzite are identifiable. All these beds of gravel decline toward the stream now, though it is not certain that they did originally. The material is perhaps less well rounded and coarser up stream, but differences are not conspicuous. Pebbles of rock from the Red Bank formation, with abundant fossils, are readily identified.

Two isolated gravel-capped hills at 160 feet and 148 feet, 1 and 2½ miles, respectively, east of Holmdel, line up with the gravel patches last mentioned. There is a series of gravel-capped hills east of Crawfords Brook, and east of Holmdel, declining from 165 feet a mile northeast of Holmdel, to 110 feet near Hop Brook, a distance of 3 miles. These might be interpreted as marking an old course of Crawfords Creek, when its channel was 80 feet higher than now.

A mile or less northwest of Holmdel are two hills with gravel at their tops at 160 and 178 feet, respectively. These are like those east of Crawfords Brook, and clearly different from the terraces along the stream here at 60 to 100 feet. The latter are regarded as of Cape May age.

Two and one-half miles southwest of Colts Neck is a hilltop bit of Bridgeton (?) at 180 feet (Taylors pit). This goes with the gravels on the hilltops 2 to 3 miles farther southwest, in the vicinity of Jerseyville.

South and southwest of Colts Neck, including the hills just noted, gravel occurs at various levels, mostly capping isolated

hills. Most of these hills range from 150 feet in altitude to 130 but the extreme range including Taylors Hill is a little greater (180–120). These various fragmentary deposits might be regarded as of different ages, or, more probably (except on Taylors Hill), as stream deposits made at different levels at about the same time. They may be of Pensauken age, but this is not determinable definitely. Cases in point may be seen 1½ miles southwest of Colts Neck (at 130 and 134 feet), and 1½ miles south of Colts Neck, at 150 feet.

Below Colts Neck, to Scobeyville and beyond, there are considerable areas at 80 to 100 feet, which have a covering of rather recent material, of nondescript character, including some wind-blown sand of recent origin. Judged by its topographic position, this material is older than Cape May, and younger than the hill-top gravels mentioned above and correlated tentatively with the Pensauken.

It may be noted that Yellow Brook, Swimming River, and Shrewsbury River follow the strike of the Cretaceous beds, and their courses were probably assumed in Pleistocene time through adjustment.

Between the Swimming River Basin and Manasquan River.— The Manasquan valley is nearly at right angles to the valley of Swimming River. From its headwaters down to Squankum, the Manasquan has cut through all the overlying beds into the Cretaceous. Below Squankum it flows over beds younger than the Cretaceous. The dip of the beds is therefore greater than the fall of the stream.

Knapp thinks Willow Brook, now tributary to Swimming River, once flowed southeast, parallel to the Manasquan, reaching the sea somewhere in the vicinity of Asbury Park. If this was the case, the Manasquan has held its course, but Willow Brook has been diverted, and the former course of its lower portion is not now evident. The adjustment perhaps did not take place till the streams had cut down to the Cretaceous. Terraces of Pleistocene material are difficult to recognize in the valley of the Manasquan, because the Pleistocene deposits, derived from the Tertiary formations, are very like the latter.

About the headwaters of the Manasquan, down to Fairfield, determinations are unsatisfactory. Exposures are few and poor, but there is a rather prevalent surfacing of gravel and sand. Two miles west of Farmingdale, in the east bank of the tributary, there is 10 to 15 feet of gravel, regarded as Cape May. Along the Manasquan there are terraces which appear to be without much Pleistocene cover.

Three miles or so east of Freehold are some hills at about 200+ feet which are without gravel other than that which goes with the pre-Pleistocene of the region. Near them are other hills at elevations of 140 to 150 feet with some gravel, which appears to go with the gravel of the hills between Englishtown and Wickatunk. A half mile northwest of Jerseyville, at 160 feet, there is 4 feet of gravel over Kirkwood sand. This and other remnants at similar levels seem to mark a level of accumulation at one time, perhaps during the Pensauken epoch.

Other similar hilltop gravels occur a mile or so south of Howells Station (at 145 to 150 feet), and south of Fairfield Station (at 140+ feet).

About Jerseyville gravels occur at various levels between 160 and 170 feet. Their materials were derived from the Cretaceous, Kirkwood, Cohansey, and Beacon Hill formations, and but little from the Cretaceous. The remnants are on ridges and hilltops, and are absent from the hills at 200 feet and above. They appear to agree in elevation more closely with the gravel on Taylor's Hill than with the remnants south of Fairfield, and are therefore tentatively regarded as Bridgeton, although in some respects they are like the Pensauken.

There are remnants of possible Pensauken, 1¾ miles and less, northwest of Farmingdale, at 110–130 feet. The gravel, like most of that of the region, is quartz, chert, and ironstone. But for the latter, it is very like the Beacon Hill gravel.

North of Shark River there are hilltop caps of gravel, small and rather high. West of Asbury Park and south of Wayside (Centerville) they occur at elevations of 160 to 200 feet. The higher, smaller patches are farther from the streams; the lower, larger ones nearer to them. Some of the highest are regarded as Bridgeton, but the lower areas may be Pensauken. At

Green Grove and farther north are much larger areas at elevations ranging from 130 feet down to 80 feet southeast of Hamilton (Shark River village). West of Green Grove is a long gravel patch, poorly exposed and indefinite, at 130 to 140 feet. These gravels and sands at 120 to 130 feet, and at somewhat lower levels near the sea, are perhaps Pensauken.

The patches of gravel between Manasquan Valley and Shark River are at various levels and are difficult of interpretation. Back of Manasquan, there are gravels at 50 to 65 feet which may be Pensauken. Similar areas occur farther north at Baileys Corner, New Bedford, Glendola (Hopeville), and vicinity, and reach a maximum elevation of a little more than 100 feet. These gravels are much alike, are in similar topographic positions, and are doubtless one in origin. They are unquestionably older than the Cape May formation, and apparently harmonize with those north of Shark River regarded as Pensauken.

One to two miles west of Manasquan and Brielle, there is an area of gravel (base 90 to 100 feet, surface 100 to 110 feet) which is distinctly older than that at the lower level (50 to 65 feet) a mile to the northeast. The gravel of this higher area is to be correlated with that on the divide just east of Allenwood, with that a mile and more northeast of Allaire, and with that in several small areas northwest of Glendola (Hopeville). The gravels in these several places range up to 150 feet or so. They seem to be rather low for Bridgeton, and too high for Pensauken, but it is more probable that they belong with the former than with the latter.

Their correlation with the small gravel caps of the higher isolated hills south and west of Wayside seems on the whole most satisfactory, particularly since in both regions these areas cap divides or isolated hills, and in both there are two series of gravel deposits at lower levels. It follows from the above that the large gravel areas northwest of Manasquan, at Baileys Corner, near New Bedford, at Wall, and Glendola, are correlated with the areas at Hamilton and the larger areas south and west of Green Grove. Probably the gravel at Shark River station and near Shafto's Corners belongs here also. All these are

regarded as probably Pensauken. It is recognized that other correlations might be made, and that in some of its details the one suggested may be erroneous. Variations in elevation are to be expected in deposits of the same age laid down in adjoining drainage basins, even at equal distances from the sea.

South of Manasquan River.—From the preceding pages, it is clear that the correlation of any gravels and sands on the Atlantic slope with the Pensauken of the Raritan Bay-Trenton-Salem belt, becomes increasingly difficult as distance from that belt increases. The correlations of the Quaternary deposits in the upper basins of the streams flowing northward and westward to the Raritan and the Delaware, are somewhat uncertain at many points. Those in the basin of Swimming River are made with large reservations, and in the basin of Manasquan River there is still more doubt; so much, indeed, as to make the attempt at detailed correlation futile. Gravels and sands of Pensauken age doubtless exist south of the Manasquan River, as north of it, but their differentiation from the Bridgeton and other post-Miocene formations becomes less and less satisfactory toward the southeast.

The general fact, as now understood, seems to be that the surface of the Beacon Hill formation, in post-Beacon Hill time, declined steadily to the southeast, at an angle which corresponded roughly with the dip of the older Coastal Plain beds. During the period of erosion which followed, the valleys cut in the surface of the Beacon Hill formation were not very deep, and probably not very wide, as the porous nature of the Beacon Hill and Cohansey formations did not favor great surface run-off. Southeast of a line drawn from Bridgeton to Red Bank, it is doubtful if the Beacon Hill and Cohansey formations were ever cut through more than locally, by the streams.

Later, in the period of Bridgeton deposition, the valleys in the Beacon Hill and Cohansey formations were probably aggraded, but with material derived from these formations, and at the northwest, from older formations as well. The Bridgeton deposits therefore which are believed to be on the southeastern slope are not very distinct, lithologically or topographically, from the older beds on which they rest. The principal difference in

constitution should be the presence in the younger formation of bits of conglomerate and sandstone from the former, showing cementation of the older formation before the deposition of the younger. But cementation of the older formations here is not prevalent, and the absence of good exposures in most of the region does not favor the application of what seems to be, theoretically, a good criterion.

During the interval of erosion which followed the deposition of the Bridgeton beds, degradation followed the same general course as before. The extent of the erosion at this time has not been determined, and is not readily determinable. It may be that a large part of the ill-defined Bridgeton of this region was removed at this time.

Then followed the epoch of Pensauken deposition, when the deposits made in the valleys were the same in kind as those of the Bridgeton epoch. In case the post-Bridgeton streams had not cut through the Bridgeton deposits, the Pensauken deposits would hardly be distinguishable from the older sediments, unless on topographic grounds, and these grounds are wanting. It is not known how high the land stood relative to sea level in either epoch. No shore lines are to be found, and no fossils are available.

Furthermore much of the region is but sparsely populated, and much of it is in timber. Exposures and sections are therefore few, and over great areas, altogether wanting, and there is only the surface sand and gravel on which to base judgment. Topographic features are feebly developed, and topography therefore helps little except at low levels.

Gravels which are either Bridgeton or Pensauken or both, can be located at many points, but a complete list of such places would not be very instructive. Some of the larger or more significant are mentioned below: (1) East of Toms River (stream) between the cities of Lakewood and Toms River, at elevations of 150 feet at the north to 30 at the south, (2) on the divide in direct line between Toms River (city) and Lakehurst, from 100 to 40 feet, (3) about Barnegat Park, from 70 to 40 feet, (4) at Whitings at many points on uplands south

of Whitings and north of Mullica River, from 200 to 100 feet, (5) considerable areas on the divide about the basin of Absecon Creek, at altitudes ranging from 80 feet to 50 feet, (6) on the upland between Mullica and Egg Harbor Rivers, from 50 feet near the coast up to 90 or so inland, (7) between Great Egg Harbor River and Maurice River, especially north of Manumuskin, at 110 feet or so at the north to 70 feet at the south, and (8) on the uplands between Maurice River and Cohansey Creek, especially south of Vineland and Bridgeton. There may be much Pensauken undifferentiated from the Bridgeton in the great area bounded roughly by Glassboro, Berlin, Atco, Landisville, Vineland, Bridgeton, Roadstown, and Aldine.

CHAPTER IV.

THE CAPE MAY FORMATION.

CONTENTS.

General Description.

POST-PENSAUKEN EROSION.

After the deposition of the Pensauken formation, a long period ensued when conditions favored erosion where deposition had just taken place. During this epoch of erosion the Pensauken formation was removed from large areas, and dissected to about its present condition in others. In the great lowland which extended from Raritan Bay to Salem by way of Trenton and Bordentown, the formation was greatly reduced in many places where it was not altogether removed. As already indicated, it is not certain that its original thickness remains at any point, though it probably does in some places between South Amboy and Delaware River. From Bordentown to Salem, its remnants are more meager.

This long epoch of erosion preceded the last glacial epoch. The details of its history are recorded chiefly in the fragmentary condition of the formation last deposited. It would appear that

the land stood somewhat higher than now, relative to sea level, during some part of this interval, for in some places valleys were cut down a little below sea level. The great duration of the period is indicated by the great width of the valleys cut by larger streams in and through the Pensauken formation.

DEPOSITION OF THE CAPE MAY GRAVEL.

Date.—After this period of erosion there followed an epoch when deposition again became important. Deposits were made both in the valleys and on the low lands about the coast up to levels of 40 or 50 feet at least. The date of this epoch of deposition can be fixed more definitely than that of some of the preceding events, for it was coincident with the last glacial epoch, when a continental ice sheet covered the northern part of the State, its edge occupying a sinuous line from Perth Amboy to Belvidere, passing through or near Plainfield, Summit, Madison, Morristown, Denville, Dover, Budds Lake, Townsbury, and Buttzville. At this time, a large volume of ice water flowed down through the Delaware Valley, and carried glacial debris in abundance to Trenton, and in lesser amount to Camden and possibly below. It is the association of this glacially derived material in the Delaware Valley with materials not so derived in the lower Delaware, that fixes the age of this last important stage of deposition in southern New Jersey; for in the lower Delaware, the contemporaneity of the deposits made by glacial waters issuing from the ice at Belvidere, with deposits about the coast at levels up to 40 or 50 feet, is clear.

The deposits of this epoch affected not only the coastal lands and the low lands of the main valleys, but they were made in essentially all the valleys of the southern part of the State, even those parts which were far from the coast and at elevations far above sea level.

Cause.—During this epoch of deposition, the southern part of the State seems to have stood a few feet (30 to 50) lower than now. This was doubtless one cause of deposition, but not the only one. If all parts of a stream's basin were lowered by the

same amount, the flow of water would not be affected except in the part drowned. But in this epoch, deposition took place in those parts of the valleys which were well above sea level, so that something besides a lower stand of land was involved.

If with the lower stand of land, the upper parts of streams were depressed more than the lower parts, the flow of water would be more sluggish throughout, and deposition favored. Again, a change of climate might have been adequate, in itself, to cause deposition,—especially such a change as went with the glacial epoch. The cold which glaciation implies would have reduced appreciably the vegetation of the region bordering the ice, and no part of the area here under consideration was far from its edge. The reduction of vegetation would have favored erosion outside the channels of the streams, especially in a region such as southern New Jersey, where the surface formations are chiefly gravel, sand, marl, and clay. Even if precipitation was not increased, more of it doubtless fell as snow, and the melting of the snow at the season when the ground is least protected by vegetation, would have favored erosion. In this way it is believed that much detritus was gathered from the slopes and carried down to the valleys where deposition took place. If at the same time the lower ends of the valleys were depressed, their lower parts were silted up, the aggradation would have checked drainage above, and so have favored deposition above the lower ends of the valleys. This might have been effective far up the valleys of streams with low gradients, like those of southern New Jersey.

DISTRIBUTION.

In valleys.—In keeping with this conception of the deposits of this time, the sands and gravels which represent it are found at low levels about the coast and in the lower ends of the valleys, and they extend far up the valleys to elevations of 140 or 150 feet along streams which have their source in the higher parts of the Coastal Plain. The formation is named from the peninsula or cape at the southern point of the State, for all the material of Cape May, so far as exposed, belongs to this epoch.

Along the coast.—According to the conception outlined, the Cape May formation forms a nearly continuous border about the southern part of the State, from Raritan Bay to Trenton, and in addition, extends up the valleys of nearly all streams which come down to this border. How much of the formation about the coast is marine, and how much subaërial (fluvial, pluvial, etc.), is not determined. If the sea level stood 30 to 50 feet higher than now, it does not appear to have stood there, or at any other one level long, for sea cliffs of distinct and unequivocal character are essentially wanting. On the other hand, the Cape May deposits about the coast are in places distinctly terraciform, and consistent with the conception of marine origin. Distinct sea cliffs at their inland border are, however, generally wanting. In the coastal phase of the formation, the materials are not so mixed as in its valley phase. In the former situation, the sand and gravel in places at least resemble shore deposits, rather than deposits by streams and rains.

Topography.—Barring interruptions by subsequent erosion, the valley deposits, now in the form of terraces, are continuous with the coastal deposits, and the contemporaneity of the two is not open to question. At the coast, the level of the valley terraces is the same as that of the coastal phase of the formation; but they rise up stream at gradients which vary somewhat from valley to valley, being less in the lower lands and greater in the higher. In other words, the gradient of the terraces is in keeping, in a general way, with the present gradients of the streams.

It is clear, therefore, that the upper limit of the formation is not defined by a contour line. About the coast it is mostly below 50 feet; but in some of the valleys it runs up to heights three times as great, and in a few places even higher. The terraces are well defined in some places and ill defined in others. In some places they are composed wholly of Cape May material, while in others, material of this age covers, as with a veneer, a foundation of older material.

CONSTITUTION.

Comparison with the Pensauken.—Where the Cape May terraces rise up stream to the Pensauken level, as is the case in some places, it is difficult to distinguish the two formations on the basis of topography; but if good sections are available, the distinction between the two commonly is not difficult on the basis of composition and texture. The material of the younger formation is less compact and less coated with iron rust, and betrays in various ways not easily designated its lesser age. There is a marked absence of soft decomposed material, such as is often present in the older gravel, but which would naturally have been ground up in the reworking of the material in Cape May time. The material of the terraces in the valleys is unlike that of the coast in being much more mixed, much less well assorted, and much less clean. It covers broader areas in the larger valleys, and narrower areas in the smaller ones.

Fossils.—Fossils are unknown in the Cape May deposits at most points, but near Buckshutem, marine fossils are found up to elevations of 10 feet or so above tide. The deposits here in Delaware Bay are more clayey than at most places on the eastern coast, and so are better adapted to the preservation of fossils.

Local Details.

TRENTON AND EASTWARD.

Since the connection of the Cape May formation with the glacial gravel at the north is by way of the Delaware Valley, the details of the formation, so far as given here, will begin with those near Trenton, where the considerable bodies of gravel and sand of distinctly glacial origin reach their southern limit.

Vicinity of Trenton.—At Trenton and just south of it, the glacial gravels make or cover a considerable plain which has an elevation of about 60 feet, being limited at the east by that contour. The glacial-gravel plain extends half way to Bordentown, but, on the New Jersey side of the river, ends abruptly west of

White Horse and north of Crosswicks Creek. Here the Delaware swings over to the east side of its valley, and the real continuation of the Trenton gravel plain is west of the river. At Florence, the Delaware again leaves what was its eastern border in the Cape May epoch, and glacial gravel reappears there on the New Jersey side of the river.

From Trenton (Chambersburg), the formation extends northeastward in a broad belt up to Bakers Basin. Farther northeast it is continued in a narrower belt over the low divide between Shipetaukin Creek and Stony Brook, and down the valley of the latter to its junction with the Millstone River. The formation also extends up the valley of Duck Pond Run from Port Mercer, and over the low divide to the Millstone at Princeton Junction, and thence down the valley of the Millstone to the mouth of Stony Brook. Meager and dissevered remnants of the formation are also found in the valley of the Millstone from this point to its junction with the Raritan.

At Trenton, and thence to Bakers Basin, the formation is largely of gravel brought down by the Delaware from the moraine at Belvidere during the last glacial epoch. Glacial gravel is found also from Bakers Basin to the Millstone, as well as at various points along the Millstone to the Raritan. Since these gravels are a little higher at the north (70 feet at East Millstone), it is inferred that the drainage which brought them in flowed from the Raritan to the Delaware, and the composition of the gravels points to the same conclusion. It is inferred therefore that, temporarily at least, during the last glacial epoch, drainage from the Raritan came up the Millstone to Stony Brook, up the valley of that stream, and over the low divide to Assanpink Creek, and thence to the Delaware at or near Trenton. The meager remnants of glacial gravel in the valley of the Millstone may mean that glacial drainage did not follow this course long, or in large quantity.

Aside from the chief belt of the formation in the valley of Assanpink Creek, it appears in most of the minor valleys of the Raritan Bay-Trenton lowland, as (1) along Pond Run; (2) along Miry Run for several miles, rising from 60 feet or so near

the Assanpink to nearly 90 feet northeast of Newtown; (3) along the upper Assanpink, rising from 60 feet near Lawrence Station to 100 feet above New Sharon, 10 miles or so up stream; (4) along Bear Brook, rising from 60 feet near Princeton Junction to 100 feet a mile and a half west of Hightstown; (5) along the Millstone above Princeton Junction, rising to more than 100 feet above Red Tavern; and (6) along Cranbury Brook, rising to 110 feet near its source. In all these six valleys the materials of the formation were derived from the older formations of the respective drainage basins. In composition, therefore, the Cape May formation of these valleys is essentially unlike that at Trenton, in that it contains no glacial or other northern material. In general the formation in the minor valleys is not disposed in the form of distinct terraces, though it takes on a terrace-like form here and there. Rather does it border the streams, grading from the flood plains below to a fairly definite level on the slope above, a level which rises up stream. The upper limit of the formation at any point in the valley is not sharp in all cases. Especially where exposures are poor, gravel and sand brought down and deposited by the streams cannot be sharply separated in all places from slope wash derived from the Pensauken formation.

The close association of the formation with the streams, its rise up the valleys, and the fact that the materials were clearly derived from the basins in which they occur, seem to leave no doubt as to its fluvial origin.

Chambersburg (*Trenton*).—Sand and gravel pits in the vicinity of that part of Trenton known as Chambersburg show a mingling of glacial gravels and sand, with sand and gravel brought in from the east and derived from Cretaceous and younger formations. Glacial gravel and sand, and gravel and sand from the Miocene about the headwaters of Doctors Creek, are readily recognized. In some places the glacial gravels and those from the east are intimately mingled. In other places they are so related as to indicate that the amount coming in from the one source was sometimes far greater than that coming in from the other.

Pond Run.—The Cape May formation has no distinct development in the basin of this creek, above the Trenton plain; but thin deposits perhaps to be correlated with it are found over the lowland nearly to the sources of the stream. They do not constitute distinct terraces, but line the lower parts of the basin up to the Pensauken level. The most that can be said of the surface deposit over this lowland is that it is post-Pensauken, and a large part of it is no doubt Cape May.

Miry Run.—Cape May gravels and sands exist along this valley up to Newtown, but the volume of the formation is slight. Its materials are from the Cretaceous and Pensauken formations, the only formations accessible to the stream and its tributaries. The material is but a few feet above the stream, much of it in low terraces 5 to 15 feet above the bottom of the valley. In constitution it is different enough from the Pensauken (or Cretaceous) above, so that the limits of the deposits are fairly well defined in the soil.

On the uplands, especially north of Miry Run, there is some loam (and sand) which appears to be wind blown, and to contain material derived from the Trenton (glacial) gravels and sands. The same sorts of loam and sand are seen interruptedly from Miry Run to White Horse.

Assanpink Valley.—Up to Bakers Basin and Lawrence Station this creek flows through the low plain (60 feet) covered by glacial gravel; but above Lawrence Station its valley is comparable to the valleys of other creeks of the region. The stream is a long one, heading back in the Clarksburg hills; but above Lawrence Station, its valley is relatively narrow.

The Cape May deposits of this valley are nearly continuous, on the north bank of the stream, up to New Sharon, but have little development on the south side, though there is a well-defined terrace at Edinburgh, at an elevation of 80 to 90 feet, on the left bank. In the vicinity of Lawrence Station, the material is mostly sand; but farther up there is more gravel. Above Edinburgh, much of the material is in terraces, 10 to 25 feet above the stream. The terraces are for the most part ill defined, and their constitution varies much from point to point in the valley. In

the vicinity of New Sharon, there is some wind-blown sand, perhaps comparable to that along some of the creeks farther south (as Crosswicks and Doctors). Where eolian sand mantles both the Cape May and the Pensauken formations, it obscures the distinction between them, where exposures are absent.

The sand-loam over the uplands here is conspicuous in some places, especially between Assanpink Creek and Miry Run. Where it is well developed, there is, in numerous places, an undulatory topography, including some undrained depressions. This is most common about the heads of the minor tributaries. The loam here is of the same general type as that at many other places in the vicinity. It is perhaps most obvious and best differentiated from its base where the underlying formation is red shale, as at Wilburtha and Washingtons Crossing on the Delaware, or along the valley of Shabacunk Creek, between Trenton and Lawrenceville. The same type of loam recurs on the east side of the Millstone in the vicinity of East Millstone, Griggstown, Kingston, and in the vicinity of Penns Neck. The loam is, on the whole, quite unlike that along the lower Delaware and its tributaries. That along Assanpink Creek and the Delaware above, is finer and more uniform than the silts and sands of eolian origin farther south, and contains much less material which looks as if derived from the glacial valley train. On the other hand, the loam above the level of the Trenton gravel is not unlike the loam which covers the Trenton gravels and sands.

Bear Swamp.—In Bear Swamp, material of fluvio-glacial origin is less conspicuous than in other near-by areas at the same level. It is present, however, and material of similar origin has been recognized in a sand pit three-fourths of a mile southwest of Princeton Junction. These facts, taken in connection with other phenomena of the region, indicate that glacial waters flowed on all sides of the Penns Neck tract, which rises above the Cape May level. The materials in the Bear Swamp valley are finer than those in the valley of Stony Brook to the north, suggesting that the main drainage was through what is now Stony Brook valley. With Stony Brook valley filled to 60 feet with glacial gravel from the north, Millstone River would

have flowed through Bear Swamp; but the valleys of Stony Brook and Bear Swamp are so nearly at the same level that the waters flowing about the Penns Neck upland could have been diverted easily from the one route to the other.

Bear Brook.—The Cape May formation appears all along the northeast side of this short valley, well toward its source. Locally it assumes the form of definite terraces, but more commonly it is not so disposed. Its surface differs from that of the upland chiefly in being more sandy. The material consists of gravel, sand, and loam.

The upper Millstone (above Princeton Junction).—This river heads east of the Clarksburg hills, and traverses a greater range of formations than other streams of the region, except Assanpink Creek. In general it may be said that the Cape May formation of this valley consists of a thin body of material mostly on the right bank of the stream, from Red Tavern to Princeton Junction. In many places it is disposed as a distinct terrace 10 to 20 feet above the stream, composed of the loose sand and gravel characteristic of the formation. At other places the terrace form is wanting, and there is at the surface no sharp distinction between the distinctive Cape May material below, and older formations above. The indefiniteness is partly the result of the loam mantle. The material in most of the valley seems to have come largely from formations at higher levels in the vicinity, while little seems to have come down from the head of the valley. The conspicuous thing about the formation here is its definite relation to the stream. Above it, the slopes are mantled with loam which appears to stand in no definite relation to the underlying formation. Where the loam is well developed, there are undrained depressions, usually small and shallow.

In the upper reaches of the valley, in the vicinity of Bergen Mills and below, there is much sand which resembles that along Crosswicks and Doctor creeks, probably eolian in its present position. In this vicinity the valleys of Cranbury Brook and Millstone River head in the same flat, and a shallow ditch would divert one stream into the valley of the other.

In the region about the headwaters of Cranbury Brook, both branches of the Millstone, and the Assanpink (from Gravel Hill on the northeast nearly to New Sharon on the southwest), there is much material which is not easily classified. Much of it probably is of Cape May age, or of this age approximately. It is material deposited after the long erosion which followed the deposition of the Pensauken, but is not so definitely connected with the streams as the Cape May formation commonly is. This may be because it is in the region where the valleys are less well defined, and where the deposits are of the piedmont type, rather than of the distinct valley type. This material was mapped by Mr. Knapp as "undifferentiated," but it might be included with the Cape May, if that term be made to cover post-Pensauken deposits in general.

Cranbury Brook.—The Cape May formation of this valley is disposed as in the valley of the upper Millstone, being confined chiefly to the right bank of the stream. It is fairly distinct up nearly to the head of the valley. It covers the low slopes, and constitutes low benches 10 to 20 feet above the stream. The soil over the formation in this valley, as in the Millstone, is much more sandy than that of the upland. The distinction is recognized in the region by differences of farm crops.

The lower Millstone.—At Princeton Junction, the three main branches of the Millstone, Bear Brook, the upper Millstone, and Cranbury Brook, come together. There is much gravel and sand over the headlands between the lower ends of the streams. Its depth is unknown, but it goes down to and perhaps below the levels of the permanent streams. The upper surface of the formation reaches a maximum altitude of about 70 feet.

Over the gravel and associated sand there is some sand and loam, which covers higher lands as well. The loam varies from sandy to clayey. Cuts have revealed the loam as a definite mantle 8 to 10 feet thick in some places, and clearly distinct from its base. Where the loam is sandy, it is eolian, and perhaps all of it had this origin.

Just south of Kingston, there is a bit of the Cape May formation in the valley of the Millstone, east of the canal. Its upper

limit is at about 70 feet. The material consists of a mixture of glacial gravels with material derived from the Pensauken. There is here a considerable amount of glacial material similar to that at Bakers Basin at an elevation of 60 feet. Traces of the same sort of material are found in the valley above Kingston, at corresponding levels, but it is not present in quantity.

A mile north of Griggstown, on the east side of the Millstone, fluvio-glacial gravel is found in relations similar to those west of Penns Neck, opposite Princeton. The remnants are seen along the ravines which lead down to the canal. They suggest that the valley of the Millstone was once filled with glacial gravel up to the 60- to 70-foot level, most of which has since been removed. Some of the remnants appear as miniature ridges, 2 to 4 rods across, with probably 3 to 6 feet of gravel of distinctly glacial type. Between Rocky Hill and Griggstown, the merest traces of similar gravel—really little more than scattering pebbles—are found at various points and at harmonious levels.

North of East Millstone village, the same material is more abundant, and appears as definite terraces, as in the vicinity of Weston and Hillsboro. At East Millstone there is a good deal of sand at 60 to 100 feet, similar to that on the shale slope above Bakers Basin. It is probably eolian.

The disposition of this glacially derived gravel in the valley of the Millstone does not show decisively how the drainage flowed. The gravel is a bit higher at East Millstone than farther south in the vicinity of Princeton Junction and Trenton; but it is also a little higher at East Millstone than at Weston, farther north. The constitution of the gravel, while not very decisive, suggests drainage to the south, for certain sorts of pebbles characteristic of the gravel of the Delaware are not found at Princeton Junction and north.

Crosswicks Creek and Doctors Creek.—The formation has considerable development about Yardville at the lower end of Crosswicks Creek, especially below Crosswicks (village). Thence it extends up Back Creek nearly to Newtown, up Doctors Creek beyond Imlaystown, and up Crosswicks Creek to Walnford and beyond. It rises from an altitude of 60 feet near the Delaware, to 120 feet at Imlaystown some 15 miles above, an average

slope of about 4 feet per mile. The gradient increases toward the heads of the valleys.

At Yardville, the formation is 10 to 30 feet deep, and its surface elevation is about 60 feet. Back from the stream, the heavy beds of sand and gravel thin out, and the Cretaceous surface beneath rises above this level. The materials here clearly were deposited by Doctors and Crosswicks creeks. The plain at 60 feet here is the topographic equivalent of the 60-foot plain at Trenton, and their contemporaneity is not open to question. That they are not continuous is an accident of later erosion. The constitution of the formation at Yardville shows that glacial materials brought down by the Delaware did not go up the valley of Crosswicks Creek. The general absence of silt and clay in the formation at Yardville and above indicates that tributary streams were able to aggrade their valleys about as rapidly as the Delaware; otherwise the side valleys would have been ponded, and deposits of silt or clay would have been made. It is true that thin beds of clay appear, here and there, in the Cape May formation of this and other valleys, but it is exceptional. It is perhaps more common farther south than in the latitude of Crosswicks Creek, and is sufficient to suggest the local and temporary ponding of different streams.

Near the Delaware the materials are gravel, sand and loam. The loam is largely at the top, and glauconitic; locally it is so heavy as to be used for brick. The sand, which is interstratified with the gravel, is also glauconitic, more conspicuously so than the loam. The gravel is mostly fine, clearly from the fine gravel (pebbles the size of peas) of the Miocene, in the vicinity of Stone Tavern. Back from the streams, sand and loam predominate greatly over the coarser material. South of the creek below Yardville, the formation is covered with glauconitic sand and loam of eolian origin. Good exposures are seen southeast of Yardville in the bank of Crosswicks Creek, on the road to Crosswicks, and along the Allentown road. Locally there is enough dune sand to modify the surface notably. It was derived largely from the Cape May formation.

In the valley of Back Creek, the formation rises but little above its level at Yardville, and is ill defined.

Up to Crosswicks (village) the valleys of Doctors and Crosswicks creeks are close together, and the divide between them is low, and covered with the Cape May gravels and sands, which seem to have been deposited by Crosswicks, rather than by Doctors Creek. Both streams have cut through the formation, revealing the Cretaceous below. Along both creeks, the Cape May formation is developed chiefly on the right bank of the stream, and where distinctly developed, it appears in the form of terraces. The terraces are not persistent, and not always distinct, for their upland limit is ill defined in many places, because the slopes above are low and gentle, leaving the upland edge of the terrace poorly marked topographically. Along both creeks there is eolian sand on the left banks, at the levels where the Cape May should be, though the sand occurs up to levels somewhat higher than those appropriate to the Cape May formation. There is such sand on the left bank of Doctors Creek above Yardville, and on the left banks of both creeks, farther up. Along both creeks the left bank is slightly higher than the right, the excess being due to eolian deposits. In the upper parts of both valleys the formation is less well developed. Instead of appearing in the form of flat-topped terraces, it lines the valley bottoms. Its slopes toward the stream are in part at least due to erosion since the gravel and sand were deposited.

On Doctors Creek, a mile and a half northeast of Crosswicks village, there is a terrace of sand and fine gravel at an elevation of 60 feet. Up Doctors Creek, the formation rises to 90 feet at Allentown, and more rapidly above, up to a point a mile or more above Imlaystown. Three-fourths of a mile west of Allentown, there is a well-defined terrace at 70 to 80 feet, which appears to represent the height of the filling in the Cape May epoch. On the south side of the creek there are higher sands (90 to 95 feet) which are probably eolian, which seem to go with the Cape May formation, or to be subsequent to it.

At Allentown there is some 20 feet of Cape May material, more than at any point below down to Yardville, and more than at

any point above. There are well-defined terraces at points above, with 10 feet of sand and gravel, but to the eastward the formation becomes less and less well defined topographically. On the south side of the stream, the wind-developed ridges of sand persist nearly to Imlaystown, and reach a maximum altitude of more than 120 feet.

Just above Crosswicks (village) the Cape May formation is disposed as a terrace in the right bank of the creek. Its elevation is 60 feet, and its surface of loam; but exposures and data from wells show that the terrace is of gravel chiefly, alternating with minor beds of sand. In the gravel, quartz and chert are abundant, sandstone and quartzite common, and water-worn pieces of ironstone common to abundant. In other words the materials came from the Cretaceous, the Miocene, and the Pensauken formations.

In the valley of Crosswicks Creek the terraces are fairly definite more than a mile east of the village. Farther up they are feebly developed at most places, though distinct on the east side of the stream above Walnford. The formation rises to 90 feet opposite Walnford, above which point it has little certain development.

The terraces along both creeks have, as a rule, surfaces of loam, and this extends up above the terraces on both sides of both valleys, and thus constitutes a veneer over terraces and uplands alike. It is clearly not of residual origin. The idea has been entertained that it constituted a formation to be separately recognized, possibly the result of a submergence; but it seems on the whole more probable that it is eolian. This veneer of surface loam helps to conceal the from-stream limits of the Cape May formation.

At Walnford and for 3 miles below, there is a somewhat ridge-like deposit of glauconitic sand on the left side of the creek. The feeble ridge is somewhat interrupted by tributary valleys, but otherwise persistent. Just west of Walnford, the sand is highly glauconitic, but the proportion of glauconite diminishes toward the Delaware. The sand of this ridge is partially eolian, and locally a very subdued type of dune topo-

graphy is to be seen. Above Walnford the same sort of sand, probably eolian, occurs on the east side of the creek above New Egypt, up to the point where the creek turns west; but here the sand, with a disposition to become slightly ridgelike, is much interruped by side streams. The same sort of a sand ridge appears on the left bank of Doctors Creek. It is feebly developed just above Yardville, and better from a point a mile below Allentown up to within a mile or so of Imlaystown. Along this creek the sand is much less glauconitic than along Crosswicks Creek.

The phenomena of these valleys are common ones in the region, a low ridge of sand on the left banks of the streams, and a terrace on the right banks, at a somewhat lower level.

Lahaway Creek.—Along Lahaway Creek, between Hornerstown and Prospertown, there are interrupted and feeble terraces rising to 140 feet at the latter place. The terrace material ranges up to 20 feet in thickness, and is of sand and gravel, the latter more abundant near the stream. These terraces are not satisfactorily correlated. They may be of almost any age from late Pensauken to Cape May.

Along Crosswicks and Doctors creeks, there is no hesitation in correlating all the distinct terraces of gravel and sand, at an elevation of 60 feet near the lower ends of the valleys, and up to 80 feet at Walnford and 120 at Imlaystown, with the Cape May formation, and in regarding them as the time equivalents of the gravels of late glacial age at Trenton. The feeble ridges of sand on the left banks are probably mostly eolian, and of similar age.

IN THE LOWER DELAWARE DRAINAGE BASIN.

Along the Delaware; Bordentown to Florence.—From Bordentown to Florence the lowland on the New Jersey side of the Delaware is narrow, and the Cape May formation is chiefly in the valleys of the tributary streams, which have wide lowlands, relative to their own size. At Kinkora the Delaware lowland widens somewhat, though interrupted at Florence by a small area above the Cape May level.

The most distinctive thing about the Cape May formation between Bordentown and Florence is the absence of gravel of glacial origin. The filling of the Delaware Valley in the Cape May epoch, it will be remembered, was effected by (1) material brought down the Delaware, and (2) material brought in by tributaries to that stream. The central part of the valley received more of the sediment brought down the Delaware, and the sides more of that contributed by the tributary streams. The Cape May material on the east side of the river from Bordentown to Florence is of the latter sort.

Below Bordentown the filling of the Delaware seems not to have built the bottom of the valley up to 60 feet. From a maximum of 60 feet at Bordentown, the surface of the deposits of the epoch declines to about 40 feet at Florence. This may represent approximately the level of the sea during the later part of the epoch.

About Fieldsborough and Florence, the lowland along the Delaware, mostly below 40 feet, is covered with loam, 3 to 6 feet deep, much of which is heavy enough for brick. It is underlain by sand and gravel in some places, and its surface is more or less covered by eolian sand, as near Stevens Station. The loam is best developed at elevations of about 30 feet. At Fieldsborough and Kinkora there are extensive excavations at the brick yards, where the surface clay, which here replaces the usual loam, as well as the Cretaceous clay below, is used for brick. The surface clay overlies gravels of Cape May age. About a mile southwest of Kinkora a characteristic section shows:

3) 4 to 6 feet of eolian sand.
2) 5 to 7 feet of black clay.
1) 1 foot of Cape May sand.

The altitude of the surface here is about 30 feet above sea level, and the clay, which seems from its position to be the equivalent of the surface loams prevalent in the vicinity, is the last phase of the Cape May deposits here. Its exceptionally clayey character here and at few other points below, suggests slack water in spots at least during the epoch. Conditions for such deposits might arise just above the mouths of in-flowing streams

which brought in more sediments than the main stream could carry away promptly.

East of Florence, the Cretaceous is exposed at many places at elevations of 30 to 40 feet, but covered generally by Cape May gravel and sand, overlain by loam or eolian sand, or both.

Along the Delaware; Florence to Burlington.—Below Florence the area of the Cape May formation expands, and has a width of 2 to 3 miles, down to the mouth of Pensauken Creek. Gravel brought down the Delaware by glacial waters appears in this part of the valley.

A mile southwest of Florence and about half a mile back from the Delaware, a gravel pit in a low knoll at an elevation of about 30 feet shows 6 feet of gravel and sand, with many cobblestones. A third of the cobbles are of the type brought down the Delaware in the last glacial epoch,—granite, and bluish and blackish disc-like pebbles of argillaceous and arenaceous rock. Other excavations show characteristic Trenton gravel. The known depth of the gravel varies from 3 to 30 feet or more.

In and about Burlington, excavations to and even below sea level show gravel which is coarse in many places, with numerous cobbles, and many dark-colored (blue, grey, and black) pebbles of argillaceous and arenaceous rock, in the form of discoid pebbles. The sand accompanying has the black and red grains never seen east of the Delaware Valley. The sand has a greyish cast, unknown in southern New Jersey outside this valley. The same sort of gravel is found in the south bank of Assiscunk Creek, a mile and a quarter from the Delaware.

A mile northeast of Burlington and half a mile southwest of Stevens, at an elevation of 40 feet, there are fully 30 feet of Cape May gravel and sand, going down nearly or quite to sea level. The upper part of the deposit is of eastern materials, but the lower part contains gravel which came down the main valley.

Two miles east of Burlington, near the old York road, well-stratified sand, with sharp cross-bedding, is seen, but all of it is of local (eastern) origin. Glacial material seems not to have reached so far east.

Half a mile to a mile south and southeast of Stevens Station the surface of the Cape May formation is affected by an undulatory topography—sag and swell type—comparable to that affecting the Pensauken formation about Fresh Ponds. The surface elevation here is 30 to 40 feet, and the surface material precludes the eolian origin of the topography. It may be the result of the unequal settling of the underlying Cretaceous beds. Similar topography occurs at higher levels, as a mile and a quarter southeast of Bustleton, just north of the Burlington-Columbus road, at an elevation of about 80 feet.

Blacks Creek.—In the valley of this creek the Cape May formation appears on the right bank of the stream, constituting a fairly distinct terrace, the upland margin of which is ill defined in many places. In Bordentown the terrace reaches an elevation of 60 feet, and broader and more conspicuous terraces occur at 60 to 70 feet 2 or 3 miles up the creek. The well-defined terrace terminates about 3 miles above the city, where the creek changes its course. Farther up the stream, the volume of material referable to this formation is small, but it is found in meager development up Bacon Run nearly to Georgetown. South of Chesterfield and Blacks Creek, on the left banks of the several tributaries above, there is a considerable accumulation of glauconitic sand above the Cape May level,—at 80 feet south of Chesterfield and at 110 to 120 feet 2 miles farther southeast. The sand is disposed as a broad low ridge, and is probably eolian.

A mile from the Delaware, the Cretaceous surface in the slope of the valley is about 40 feet above the creek; 3 miles from the Delaware it is 25 to 30 feet above the creek; 5 miles above, 20 feet; and 7 miles above, about 5 feet. In other words, the lower end of the valley is lower now by some 40 feet than it was before the deposition of the Cape May formation, while 7 miles from the Delaware the depth of the valley is nearly the same as in the Cape May epoch. The left slope of the valley is higher and steeper than the right most of the way, and is covered with a thick mantle of loam, probably wind blown.

Loam covers the upland above the Cape May formation, and this upland loam appears to be continuous with that over the

Cape May terraces, though its character changes from place to place. Where the loam is thick, its surface is somewhat undulatory, with undrained depressions 2 to 6 feet deep. Even at high levels (180 to 200 feet) there is glauconitic loam at the surface, in places where it is not residuary, as on Miocene sand. This loam is well developed in the vicinity of Sykesville, and at some points on the divide between Sykesville and Springfield. The greensand constitutes 20 per cent. of the loam locally, though commonly much less. The eolian origin of this loam seems plausible.

Cape May deposits are developed along the small creek between Blacks Creek and Columbus Creek, but they possess no exceptional features.

Columbus Creek.—Cape May deposits extend up this valley nearly to Columbus, in a belt nearly a mile wide most of the way. Their surface rises from about 40 feet at the Delaware to about 70 feet at Columbus. Back from the Delaware the deposits are mostly on the right side of the valley. They are disposed in fairly distinct terraces with poorly defined upland borders, and with surfaces somewhat affected by eolian sand and loam. The depth of material is slight.

In Columbus there is glauconitic sand at the surface, and the same sort of material spreads to the south. Half a mile or so east of the village there is another body of similar sand mantling the divide south of the creek. These sands are comparable to those of south of Blacks Creek, and south of Rancocas Creek east of Mt. Holly.

Assiscunk Creek.—Cape May deposits are much more extensive in this valley than in the valleys of Blacks and Columbus creeks. The lower part of the valley, cut in the Raritan formation, is wide, while along the outcrops of certain overlying Cretaceous beds it is relatively narrow, as in the vicinity of Jacksonville. It widens again above Jacksonville, where its upper tributaries flow through broad flat tracts.

The general phenomena of this valley up to Jacksonville are like those of the valleys above. There are terraces, especially on the right banks, rising up stream. Their upland edges are

ill defined, and they are composed of gravel and sand, especially at their streamward edges, and they are more or less generally covered with loam. Wind-blown sand has modified the surface slightly. Where surface loam is present, it is like that at Kinkora and Fieldsborough. The terraces along the lower course of the stream are only 30 to 40 feet above tide, but the corresponding deposits rise to 60 feet or more up the valley.

The broad flats above Jacksonville appear to be covered with deposits of Cape May age, but the material is not well defined or well exposed.

Northwest and southwest of Jobstown are two ridges rising to 80–85 feet, covered by glauconitic sand which is locally as much as 20 feet thick, though this is perhaps twice its average thickness. It is like the eolian (probably) glauconitic sand along the streams. There is a bit of gravel beneath the loam, doubtfully of Pensauken age. This glauconitic sand goes with that at various points in the region, ranging in elevation from 200 feet down.

Delaware Valley; Burlington to Pensauken Creek.—Between Burlington and Rancocas Creek, the lowland bordering the Delaware is an undulating plain 2 to 4 miles wide, covered with sand and sandy loam, much of which is wind blown. Locally a distinct though feeble dune topography is developed, as 2 to 3 miles south and southwest of Burlington. Beneath the surface sand, the materials are various, but gravel is common, containing some pebbles brought down the Delaware. The plain continues southward, with the same general characteristics, to Cambridge (below Riverside). Below Cambridge it narrows, but widens again at Riverton and Palmyra. A little southeast of Edgewater Park, a section is as follows:

4) 2 to 6 feet of sand, medium fine, yellow to brown, eolian.
3) 6 feet of black clay, horizontally bedded, but with laminæ bent and distorted.
2) 10 feet of sand, the upper part very like number 4) above, the lower part containing some glacial sand.
1) Sand, with gravel—cobbles and bowlders. The stony material consists of quartz, sandstone, quartzite, and greywacke.

This section is like sections farther north except that the clay here is heavier. Except for the clay, the section is fairly normal for the region.

A few rods northeast of Edgewater Park Station, just north of the railway, there is gravel, containing even small bowlders. Pieces of Triassic shale, granite, and trap occur here, in addition to the sorts of rock enumerated above. It is worthy of note that the granites and greywackes do not look so fresh as those of the Trenton gravels generally. Similar gravel occurs in Beverly, and has been seen in temporary excavations down to depths of 10 feet. It may be seen in excavations generally between Edgewater Park and Delanco, near the river. One and a quarter miles southwest of Beverly depot, sections have been seen showing Trenton gravel (Cape May) over Pensauken, if interpretations are correct.

The gravel containing greywacke is seen again about Riverside, and at Riverton in the south bank of Pompeston Creek. Other exposures in Palmyra show greywacke gravel under the surface loam. To the southward, the sorts of pebbles characteristic of the Delaware glacial gravels become fewer and fewer.

From Burlington to Pensauken Creek, most of the Cape May formation which can be assigned to the Delaware Valley proper has a surface altitude of 30 to 40 feet, but in many places its surface has been built up by eolian sand to elevations somewhat above its original level.

Rancocas Creek.—The basin of this creek resembles the basin of Crosswicks Creek in some respects. The form of the basin, like that of Crosswicks Creek, is related to the character of the underlying formations. It is narrow where it crosses the marl series, but expands greatly above in the vicinity of Mount Holly. Arneys Mount, Mount Holly, and Mount Laurel are isolated elevations along the outcrop of the marl series, in place of the high belt in the corresponding position on Crosswicks Creek. The low flat in the basin of the upper Rancocas is larger than that in the upper basin of Crosswicks Creek, and it opens much more widely toward the Delaware lowland. These features are in keeping with the larger size of this creek, as compared with Crosswicks.

The development of this broad lowland in the upper part of the basin was accomplished before the Cape May epoch, and is represented in the vicinity of Pemberton, Vincentown, Lumberton, Medford, and Taunton. Through this lowland, the upper waters of the South Branch of the Rancocas had their courses in shallow valleys in the Cape May epoch. During this epoch, these several valleys were partly filled with sands and gravels brought down by their streams.

Between 2 and 3 miles from the Delaware, the Cape May formation is seen in excavations. It appears to represent material worked over from the Pensauken and older formations, and contains coarse materials, up to the size of bowlders. It is not disposed in well-defined terraces. A mile and a half west of Rancocas village there is a distinct terrace at an elevation of about 25 feet, with coarse material (gravel and sand) above, and finer (glauconitic sand) below. Heavy brown loam, like that at Pemberton, appears up to elevations of about 30 feet, especially on the left bank of the stream.

In the vicinity of Hainesport, distinct Cape May sand and gravel occur at elevations of 40 feet or so, but the stream deposits are more or less covered by eolian sand. Between the eolian sand and the river sand and gravel, there is some loam, used as moulding sand. Just north of Timbuctoo, brick yards use a heavy surface clay, 2 to 6 feet deep, which overlies Cape May sand and gravel. The clay has an elevation of 30 to 40 feet. It corresponds to the Kinkora loam and the Edgewater clay, and overlies the gravel and sand of the Cape May formation in this region.

Glauconitic loam of uncertain origin and age overlies the divide at 70 feet, north of Timbuctoo. It overlies glauconitic sand which is well stratified, and carries a bit of gravel. In the vicinity of Mount Holly, the Cape May formation appears as a distinct terrace on the left bank of the stream, made up (as one-fourth of a mile southwest of depot) of 20 feet or so of stratified gravel and sand. Little distinctive Cape May material is found in the north branch of the valley above Smithville, and little in the south branch above Vincentown, though there are

local terraces at Smithville and Birmingham at 50 feet, and indistinct terraces probably of the same age, at Pemberton and New Lisbon at higher levels. Sand and loam, perhaps blown up from the Cape May level, overspread higher lands.

The left bank of the North Branch of the Rancocas is bordered from Pemberton to Mount Holly by a low ridge of sand similar to that in corresponding positions along Crosswicks, Blacks, and Doctors creeks. At Birmingham, the sand has been extensively worked for use in asphalt paving. It is coarse, sharp, of uniform grain, and very free from earthy matter. It forms a low ridge, the top of which is 60 to 80 feet above sea level. Its relations are the same as those of the sand along the south side of Crosswicks Creek at Crosswicks, and Blacks Creek at Chesterfield. These peculiar sands appear in other valleys above the point where the Cape May terraces are well developed.

Over broad areas at levels of about 60 feet in the vicinity of Pemberton, there is a covering of 3 to 10 feet of sand, gravel, and loam, of uncertain correlation, but apparently largely of Cape May age. It does not constitute a terrace, but a general, flatland covering. It is not much exposed, and its relations are not firmly established.

On the south slope of Arneys Mount, at an elevation of 150 feet, there is a considerable thickness (20 feet or so) of glauconitic loam and sand. Similar loam in much lesser quantity is found on other parts of the slopes of this mount, lying on Miocene sand. Its relations are the same as those of the green loam in the vicinity of Jacobstown and Sykesville, and its origin is doubtless the same. Farther north similar loam extends along the divide from Jacobstown to Sykesville, and thence to Springfield and Fountain Green. Within this general area, it reaches levels of 180 to 200 feet, without having well-defined limits. It is probably eolian, though the heaviness of the loam at many places does not at first suggest this origin.

In the basin of the South Branch of Rancocas Creek, the Cape May formation has greater development. It covers most of the area below 50 feet on both sides of the stream and its tributaries, and rises little up stream for considerable distances because

broad areas along the streams remain low up to Taunton (above Medford). Two or three miles above Medford the differentiation of the surface formations becomes impracticable. Up the creeks which extend eastward to Vincentown and beyond, the formation spreads widely, but remains low, mostly below 50 feet up to Buddtown on Stop-the-Jade, a mile above Retreat on Cedar Run, up nearly to Friendship on the creek of that name, and up to Beaverville, on Beaver Dam River.

The formation is best developed, and certainly best exposed, northwest of Hainesport. Here the gravels and sands rise to 30–40 feet, and go down to tide level. The formation makes up most of the material above sea level between the north and south branches of the stream back 2 miles or so from their junction. It is partly covered by eolian sand. The material exposed in the pits below Hainesport is well stratified. It is mostly sand, but seams of gravel run through it, locally developing into beds a foot or so thick. On the west side of the stream a mile above Hainesport similar materials appear, but their base is 10 to 15 feet above tide level.

Farther up the valley, the same relations hold, but the formation gets thinner and thinner as the surface of the underlying Cretaceous rises. In the vicinity of Eayrstown, the base of the gravel is about 30 feet above sea level, but the surface of the formation has risen less, and the formation is therefore thinner. At Lumberton, the sand and gravel are some 20 feet thick near the stream, but thin out back from the stream, with no well-defined upland edge. The stratification also is much more definite near the streams, disappearing or becoming indistinct toward the uplands.

Below Pemberton and Medford, both valleys were wide in the Cape May epoch. As the Delaware Valley was filled up, either by deposits or by water, the headwaters of both branches of the Rancocas, coming down from Miocene and younger beds to the east, brought much sand and gravel with which they aggraded their valleys. The formations accessible furnished much sand and little gravel, and the filling corresponds. After the streams reached the Cretaceous outcrops, materials from these formations

were added to the materials from younger formations brought down from above. Glauconitic is the contribution of the Cretaceous most easily recognized.

As the valley was aggraded by its stream, the side drainage, including general slope wash, was depositing its appropriate materials along the edges of the valley bottom at the bases of the valley slopes. This material was more strictly local. Thus it happens that in the central part of the valley at Eayrstown and Lumberton, much of the material was from the Miocene and younger beds above, while along the sides, more was derived from the Cretaceous.

Up stream, as at Chairville, the Cape May deposits run up to the level of Pensauken or post-Pensauken deposits, and become difficult of differentiation. As the valleys become narrower, the formation is less well developed, and merges into modern deposits.

Lumberton loam.—Years ago foundries began using loam obtained from the vicinity of Lumberton. It was obtained chiefly north of Lumberton, just beneath the soil which was stripped off to the depth of 4 to 6 inches. The value of the loam for this purpose was so great that foundry interests now control much land about Lumberton. In places the soil which is stripped off is replaced after the loam beneath is removed, and tillage goes on as before. This loam is found at the Cape May level, but is not so confined. It is dug to some extent up to levels of 80 feet. While not confined to the Cape May formation, therefore, it is characteristic of that formation, and appears to be connected with it in origin.

Swedes Run and Pompeston Creek.—Up Swedes Run, the Cape May formation rises to 50 feet or so a mile above Chesterville. Where the valley opens out into the Delaware lowland there is a terrace of 20 feet of gravel and sand on the south bank of the stream, at a level of 35 feet. Terraces at similar levels occur elsewhere along this run.

The phenomena in Swedes Run are duplicated in the valley of Pompeston Creek, whose Cape May deposits connect with those of Pensauken Creek east of Parry. The benches along

Pompeston Creek show that the Delaware here was filled up to the level of about 40 feet.

Pensauken Creek.—The Cape May deposits of this valley connect with contemporaneous deposits of the Delaware at Palmyra, and are continuous up to Mount Laurel and Cropwell. Their great expansion in area is between Moorestown and Mount Laurel, over the broad tract of lowland in this region.

Near North Pennsville there are feeble terraces, and they are continued for a mile or more to the east; but the depth of the Cape May deposits is slight, and they do not appear to correspond with the level to which the Delaware was filled in this epoch. They are probably remnants of plains of degradation developed after the Cape May epoch.

Up to the junction of the North and South branches of Pensauken Creek distinct terraces have little development; but between the North and South branches the formation is well seen, consisting of loose gravel and sand, rising to the 20–25 foot level.

Along the North Branch, between Lenola Station and Perry, there are many sharply defined bench-like areas at 20–30 feet, which have a thin covering of Cape May material; but along this branch the formation has little representation up to Moorestown. Above this place, the valley opens out into a wide flat, 30–50 feet in elevation, toward Mount Laurel, and this flat has a thin surface veneer of material which is probably to be correlated with the Cape May formation. In the vicinity of Wilsons Station there are distinct terraces at 20 to 30 feet, but they are of Cretaceous clays.

Along South Branch, Cape May terraces are better developed. The most conspicuous is on the north side of the creek, a mile or so west of the Moorestown-Ellisburg pike. The terrace here is 30 to 40 feet above sea level, but the Cape May sand and gravel are not more than 10 feet deep on the average. Good exposures of the formation have been seen half a mile west of Mapleshade in the east bank of the stream, in the point of the headland between Pensauken Creek and a small tributary which

enters from the northward; also south of Mapleshade and below the Moorestown water works.

The formation continues up the valley nearly to Cropwell where it reaches an altitude of 70 to 80 feet, but its upper limit is not well defined.

The left banks of both branches of Pensauken Creek are steep, and the right ones rise gently. The left banks, however, do not have distinct ridges of sand, like the valleys of Rancocas and Crosswicks Creeks.

The divide between the two branches of the creek west of the Moorestown-Ellisburg pike has a distinctly undulatory topography, at the 40 to 60-foot level. The region is underlain by a clay member of the Cretaceous,—the type of formation which underlies other areas of comparable topography.

Delaware Valley—Pensauken Creek to Coopers Creek.—Between these creeks the Delaware lowland is very narrow, and from Delaire to Pavonia nearly wanting most of the way. Below Pavonia the lowland and the Cape May formation expand, extending broadly up Coopers Creek to Cooperstown, and covering the lowland nearly to the headwaters of Newton Creek. The area of the formation along the Delaware narrows again between Big Timber and Little Timber Creeks.

The upper limit of the Cape May formation is not well defined everywhere, though at some points there is a topographic break which is assumed to mark its limit. It is not disposed in the form of a terrace or well-defined flat, and its surface has been somewhat modified by wind; but from Pavonia to Westville it covers the surface generally up to elevations of 40 feet or so. This may be looked upon as its normal level in the Delaware Valley here. At lower levels its surface has been degraded.

Coopers Creek.—Up this valley the formation rises from 40 feet near the Delaware, to 50 at Haddonfield, 70 at Gibbsborough, and even a little higher near the headwaters of some of the tributary streams. The material is disposed to some extent in the form of terraces, as 3 miles from the Delaware on the south side of the stream. The base of the formation here is below sea level, and its top about 20 feet above; but it is doubt-

ful if the present surface of the terrace represents the original surface of the formation. A little eolian sand mantles the surface at many points. Up the valley the phenomena of the lower part are repeated with such changes in composition of material and height as go with river deposits. Loam mantles the upland back of the terraces, and appears to be continuous with the surface loam of the terraces.

Some 12 miles up the stream there is a high hill, 181 feet in elevation, capped with Bridgeton gravel, and mantled with glauconitic loams. Seams of sand are interbedded with the loam, and in some of these seams, more than half the material is green sand. This loam is like that on Arneys Mount (p. —), and in both cases is far above any present source. Either the glauconite has been carried up by wind, or sources which were once higher have been worn away. The former is the more probable. Green loam does not appear at the surface elsewhere in the vicinity.

Newtons Creek.—Most of the basin of this creek is below the level of the top of the Cape May formation. The low surface is covered with 5 to 10 feet of loam, sand, or gravel. The gravel and sand are chiefly near the streams, and the loam back from them. It is here impossible to separate Cape May material from that of lesser age, in any thorough-going way.

Big Timber Creek.—In the basin of this creek, the interstream areas are higher than in the basin of Cooper Creek, and the valleys are deeper, broader, and more trough-like. The left slopes of the valleys are higher and steeper than the right, though the difference is not as conspicuous as in the valley of the Pensauken, and some other creeks. The Miocene hills in the upper part of the basin, and the arenaceous beds of the Cretaceous, give the region a sandiness which does not facilitate the working out of its surface geology.

At the lower end of the valley the Cape May material extends below sea level. In the vicinity of Westville all the material above sea level is of this age. Farther up the stream the valley narrows, and the formation appears in narrow strips on one or both sides (chiefly on the right) up to Prossers Mills, where it has an elevation of 80 feet at least. Up the North Branch

it extends eastward to Laurel Springs and Clementon, and northward to Magnolia, reaching an altitude of nearly 100 feet.

A mile and a half east of Westville, the Cape May gravels and sands are well developed where a small tributary comes in from the south. The narrow belt between Big Timber Creek and Beaver Brook appears to be of the same sort of material. At Chews Landing and below, on the right bank of the North Branch, there is a Cape May terrace, with 10 to 15 feet of sand and gravel. A mile above Chews Landing the terrace is lower,—probably not retaining the original surface of the formation.

A mile above Chews Landing, the Cape May material is seen to be loose, clean sand, with a little gravel scattered through it, the whole well stratified. East of Chews Landing, there is a nearly continuous series of terraces (really one terrace interrupted by erosion), but exposures are few. At Laurel Springs and Garden Lake, the deposit is thin, and not sharply limited. Similar deposits border Otter Brook, rising to 60 to 70 feet.

A terrace of the same formation appears on the right bank of the lower part of Almonesson Creek, and in the main valley to the east. It is well developed just above the junction of the North and South Branches of Big Timber Creek, where its material has a thickness of 20 to 30 feet, and its upper surface a height of about 50 feet. In constitution it is very like the sand and gravel at Westville.

At Mechanicsville 20 feet of gravel and sand form a terrace whose surface is 50 feet above tide. Above Greenlock, Cape May sands and gravels rise to the Pensauken level, and the separation of the two becomes uncertain or impossible on topographic grounds. Much of the material in the upper parts of the valleys seems to have been brought to the valley by side wash, rather than by the current of the main stream.

The terrace remnants show that Timber Creek Valley was filled to 30 feet at Westville, to 40 feet at Clements Bridge, to 60 feet at Blackwood, and to about 70 feet at Turnersville, Clementon, and Laurel Springs. Loam, as the last phase of the formation, is less conspicuous here than along most of the

streams tributary to the lower Delaware. Eolian sand has modified the surface to some extent.

Woodbury Creek.—There are some terraces along the lower course of Woodbury Creek, but in many places the sands and gravels of Cape May age are not disposed in this form. Terraces appear where Mathews Brook comes in; also on the north bank of Woodbury Creek just west of Woodbury; but these are low and probably degradational. The Cape May sands and gravels are mostly on the north side of the stream.

Mantua Creek.—The Cape May formation of this valley merges into that of the Delaware proper a little below Berkley. At Berkley, and between that place and Paulsboro there is a terrace at 20 to 30 feet which appears to represent the upper limit of aggradation here during the Cape May epoch. It is doubtful, however, if all the lowland of the vicinity was ever built up to this level, though the lower end of the valley of Mantua Creek was.

The Cape May sand is well seen in a terrace 20 to 25 feet above tide a little west of Berkley, and in greater volume just above the junction of Mantua Creek and Edwards Run. The surface is much affected by wind-blown sand. Half a mile west of Mantua there is a terrace at 40 feet covered with about 10 feet of gravel and sand. There is a similar terrace half a mile east of Mantua.

Between Mantua Creek and Monongahela Brook, there is a terrace at 40 feet, covered with 20 feet of sand and gravel. A mile or so east of Wenonah, there is a terrace on the right bank of Mantua Creek, at an elevation of about 60 feet. Its upper 20 feet is of Cape May sand and gravel, loam-covered, resting on Cretaceous beds. The formation is represented up nearly to the sources of the streams which join to make Mantua Creek, that is up to points a mile or more above Hurffville, 2 miles above Dilkesborough, and a mile above Pitman Grove. The surface of the formation rises from about 40 feet at Mount Royal, to nearly 50 feet just above Wenonah, to 70 feet at Hurffville, to 90 or more at Dilkesborough, and to 120 feet east of Glassboro. Up Chestnut Branch it rises to 100 feet or so west of Pitman Grove.

In this basin, as in those farther north, there is a strong contrast between the steep left slopes of the valleys, and the gentler slopes on the right where the Cape May formation is chiefly developed.

Three or four miles back from the Delaware, the low divides between the tributary streams are covered with 2 to 4 feet of loam which was not derived from the formations beneath. Farther from the Delaware, the surface material on the uplands seems, in general, derivable from beds beneath. The loam over the Delaware lowlands seems much like that over the uplands. The latter may have been derived from the former, having been shifted and re-deposited.

The Delaware lowland between Mantua Creek and Raccoon Creek.—The Delaware lowland here has a width of 3 to 4 miles. Most of it is below 20 feet, but some parts rise to 30. Tidal marshes occupy half the area, and the remainder is covered with loam or sand, wind-blown sand being common. Along the streams there are in places 2 to 6 feet of sand and gravel; but it does not extend back far from the water courses.

In the region about Gibbstown, Repaupo, and Bridgeport, there is little material that can be definitely correlated with the Cape May formation. There is a thin veneer of loam in many places, a foot or two thick, which is perhaps to be so classed; but there are also areas of nearly bare Cretaceous at various levels, from 10 feet up.

Beneath the thin covering of sand and loam lies the Cretaceous. If all its superficial cover were removed, the Cretaceous surface would not be very unlike the present surface. The sand beds of the Cretaceous were doubtless the source of much of the sand which has been blown about, making district dunes in places, as half a mile southwest of Paulsboro, and about Bridgeport. It does not appear that deposition was ever heavy over this lowland, yet it is certain that the tributary valleys were filled up to what is now the level of 30 feet or so, where they join the Delaware lowland. If the Cape May deposits once filled the Delaware to the same level, they have been removed, and this seems hardly probable. The amount of post-Cape May

erosion which this hypothesis implies seems excessive. The alternative seems to be that this region was an estuary while the side valleys were filled, and that the central part of the estuary received little sediment.

The Cape May deposits cover most of the area drained by the smaller creeks, and form narrow borders along the larger ones which reach back into the higher land above Mickleton and Asbury Station.

Raccoon Creek.—The Cape May formation in this valley extends well up to the headwaters of the stream and its chief tributaries. Its surface rises from 30 feet or less on the Delaware lowland, to more than 100 feet above Ewans Mills, 5 miles above Mullica Hill.

On the Delaware flat and in the lower part of the Raccoon Valley, the Cape May material is not abundant. It consists of gravel and sand which cover the Cretaceous beds to the depth of a few feet. The gravel is more abundant near the stream, and finer material farther from it. The material takes the form of terraces, or covers Cretaceous benches, but its surface does not rise much above 40 feet up to Swedesboro. Half a mile below this place, the sand and gravel are 20 feet deep, and the surface of the terrace about 35 feet above tide.

Just west of Swedesboro, on the south side of the stream there is a remarkably flat terrace at about 30 feet, composed of well stratified, incoherent sand and gravel. The gravel is fine, the pebbles being mostly less than an inch in diameter, and clean and fresh. The valley here was built up to 35 feet or so during the epoch, with material brought down by the stream. The material of Raccoon Valley is coarser than that of the Delaware, where there may have been an estuary, or, at most, a very sluggish current, at the time.

A mile and a half above Swedesboro there is also a distinct terrace at about 35 feet; but the depth of sand and gravel is only 10 feet, and there is more gravel than below. All the stony material is of resistant sorts,—quartz, chert, ironstone, etc. A layer of mud appears in the section here, near its base.

A quarter of a mile below the mouth of the South Branch of Raccoon Creek there is a distinct terrace at 50 feet, but only the uppermost 10 feet or so of its material is younger than the Cretaceous. A mile below Mullica Hill there is a conspicuous bench at 60 feet, with 10 feet of gravel and sand over the Cretaceous.

Farther up the creek and its tributaries, the phenomena of their lower courses are continued at higher levels. In general, the deposits are not so high above the streams in their upper courses, but their elevation above sea level is greater. As in most of the other valleys, the Cape May deposits are mostly on the right banks of the streams.

The Salem Plain.—Below Camden, the Delaware plain has not a heavy covering of the Cape May formation. In general it is thinner above Raccoon Creek than below. Above, it ranges from 0 to 20 feet, though rarely more than 10 feet. The Cretaceous appears at the surface in many places; but below Raccoon Creek, and especially below Oldmans Creek, the Cape May gravel, sand, and loam, form a nearly continuous cover. This cover transforms the plain into good farming land, as in the vicinity of Salem.

Oldmans Creek.—In the valley of this creek, the formation here under consideration rises from an elevation of about 30 feet where the valley joins the Delaware lowland, to 90 feet or so at Avis Mills. In keeping with the general configuration of the valley, it appears mostly on the north side of the stream. It constitutes terraces in some places, but more commonly it caps benches of Cretaceous strata, shaping them up into terrace form, by building up their streamward edges.

Where the valley joins the Delaware lowland, there is a 20-foot terrace of gravel and sand on the left bank of the stream, affected by more or less eolian sand. At Auburn there is a bench on the north side of the stream, at 35 feet, and the formation goes down to within about 10 feet of tide level, and has a bed of clayey matter near its base. At Harrisonville Station, 7 feet of stratified gravel and sand are referred to this formation. On the left bank of the stream at this point 4 feet of greenish marly

loam overlie gravels of greater age than Cape May, and at higher levels. Between Harrisonville Station and Harrisonville, there is a bed of clayey matter in the terrace of the headland between Oldmans Creek and the tributary from the south. At Harrisonville the Cape May gravels and sands rise to 70 feet; but here and farther up the valley, the differentiation of Cape May gravels from the valley phase of the Pensauken is difficult.

Salem Creek.—The phenomena along Salem Creek duplicate those along the creeks farther north. Where the valley merges into the Delaware lowland a mile or so below Sharptown, the Cape May formation reaches an elevation of about 30 feet, though much of its surface is lower. It rises to 50 feet at Woodstown, 70 feet at Richmanville, and 80 to 90 feet 2 miles farther up. The formation is developed chiefly on the right banks of both main and tributary streams (Majors Run and Nihomus Run). South of Woodstown the formation of the main valley joins that of Nihomus Run to the south.

At Courses Landing 10 feet of well-stratified fine gravel and sand appear on the left bank, while on the right, 10 to 15 feet of stratified gravel is covered by 5 to 10 feet of eolian sand. Beneath the lower gravel and sand is gritty clay, probably also of Cape May age.

At Sharpstown, there is a terrace at 25 feet, with 10 to 15 feet of sand and gravel over clay marl. Just east of Woodstown, there are terraces on both sides of the stream at 50 feet, with 10 to 20 feet of Cape May sand and gravel; and at Richmanville at 60 feet, on the right bank. There are other terrace remnants a mile and a half above the last-named place.

Mannington Creek.—A mile and a half from Salem Creek, the left bank of Mannington Creek shows 20 feet of gravel and sand, referable to the Cape May formation. This material is singular for its considerable content of cobbles and bowlders. One bowlder was seen here, with glacial striæ on two sides. At Welchville there is a 20-foot bench in which exposures show, near the base, sand which is not distinguishable from Pensauken sand.

In general the Cape May mantle in the valley is thin, and back from the streams is of clay and loam. It connects with that of Alloways Creek by way of Alloway Station.

Alloways Creek.—A mile below Quinton, a section in the flat at 20 feet shows

2) 3 feet of brown sandy loam.
1) 6 feet stratified white sand, with seams of fine gravel.
Base unknown.

This is fairly typical for the Cape May formation of this region.

A mile and a half above Quinton a section in the 25-foot terrace shows

2) 3 feet brown sandy loam.
1) 7 feet yellowish sand, coarse and fine, carrying seams of fine gravel, horizontally stratified.
Miocene, surface 10 to 15 feet above tide.

Half a mile west of Alloway, there is a terrace at 30 to 35 feet, which shows 20 to 25 feet of gravel and sand, underlain by Miocene clay. At Alloway, the Cape May terrace has an altitude of 40 feet. Above Alloway, the formation has some development up to altitudes of 50 feet, but not along the stream. It is seen to rest on the Miocene at some places.

Cohansey Creek.—South of Salem Creek, the Cape May formation expands to the eastward, and borders the bay much as it borders the river farther north. It is found along Cohansey Creek in a narrowing belt up to Dutch Neck, with an upper limit of about 40 feet. It covers a considerable area on the west side of the creek between Dutch Neck and Bridgeton, rising nearly or quite to 50 feet at the latter place, and to 60 or 70 feet near Cedar Grove. Above Bridgeton, however, its development is slight and in most places not very distinct.

On the right bank of Cohansey Creek the Cape May formation covers all the lowland south of Fairton, and overspreads a belt several miles wide along the bay farther east. Its landward limit, roughly defined by the railway from Fairton to Mauricetown Station, has an elevation of about 40 feet; but

most of the tract covered by it between Cohansey Creek and Maurice River has an elevation of less than 20 feet.

Maurice River.—Up Maurice River it appears in a characteristic way on both sides of the stream nearly to Franklinville, and perhaps beyond, though it here becomes indistinguishable. It covers a belt several miles wide up to Millville, and a narrower belt farther north. It also covers a wide belt in the lower parts of the valleys of Manumuskin and Manantico creeks, extending up nearly to Bennetts Mill in the former valley, and to Hange's Bridge in the latter.

In the valley of Maurice River it attains an elevation of 90 to 100 feet in the vicinity of Porchtown and Malaga, 90 feet at Union Grove on the tributary east of Rosenhayn, and about 60 feet in the valleys of Manantico and Munumuskin creeks.

The material of the formation was derived from the Bridgeton, Pensauken, and Tertiary formations of the drainage basin. It is sandy for the most part, and but little of the land covered by it is cleared. There are few exposures, and detailed study of it has not been made. Eolian sand affects its surface at some points, as along the railway west of Vineland.

East of Maurice River the formation expands widely, covering most of the area south of a line running from Manumuskin to Great Egg Harbor, though an area of a few square miles east of Bricksboro rises above the level of the formation, which seems to be limited approximately by the 40-foot contour.

IN THE ATLANTIC DRAINAGE BASIN.

Great Egg Harbor River.—The formation extends up the valley of Great Egg Harbor River to Weymouth, several miles above Mays Landing, in a broad belt on both sides of the stream. In narrower and ill-defined belts, it is found still farther up the valley, but it nowhere rises above 50 feet or so, in distinguishable development. Above Weymouth it is doubtless represented under the marshy bottoms of the valleys.

Between Great Egg Harbor River and Toms River.—East of Great Egg Harbor River, it is limited chiefly to elevations below 35 feet. It expands in bay-like form in the lower part of

the valley of Patcong Creek. In the vicinity of Pleasantville, older formation (above 35 to 40 feet) extend out to within less than a mile of the salt marshes, but the formation expands again over a bay-like area in the lower part of Absecon Creek, extending up to Doughty's and beyond. Just above Absecon it narrows to belt less than a mile wide at Leeds Point, but expands greatly in the valley of Mullica River, above Great Bay. Here it covers a large area of lowland, from Leeds Point to Smithville, Hewittville, Unionville, and Batsto. It extends up Wading River, tributary to the Mullica, several miles above Harrisonville, reaching an elevation of more than 100 feet, and covers most of the area south of a line from Harrisonville to Nugentown. In most of this area it is confined to levels slightly below 40 feet, but near the heads of the valleys it rises a little higher. It is hardly recognizable above elevations of 50 feet. West of Tuckerton there is an area of some older formation (Pensauken?) rising above the Cape May level (40 feet).

There is some expansion of the formation up the valleys of Shords Mill Brook above Tuckerton, and up Westecunk Creek above West Creek. A mile north of Cox's Station, older formations extended east to the railway, and the Cape May border is narrow to Manahawkin, being restricted virtually to the coastal belt less than 35 feet in elevation. At Manahawkin it again widens, but to the eastward, rather than inland. Cape May deposits here are hardly separable from younger deposits.

The formation is wanting some of the way between Manahawkin and Barnegat, but from the latter place to Toms River it forms a belt 1 to 2 miles wide most of the way, and expands up Ewing Valley, holding quite strictly to levels of less than 40 feet along the coast, but rising slightly up the valleys. Up Cedar Creek, for example, it reaches an elevation of 60 feet at Dover Forge, and more than 100 feet at Webbs Mill.

Toms River.—About the mouth of Toms River, the Cape May formation retains its habits of the region farther south, being restricted to the area below 35 feet along the coast, and covering most such areas.

Island Heights is of older beds, but the Cape May formation extends up Toms River and its principal tributaries, in rather

narrow belts on both sides of most of the valleys. Up Davenports Branch, it is restricted chiefly to the left bank, and reaches an altitude of more than 100 feet a mile or two southeast of Whitings. It reaches an altitude of 70 or 80 feet at Lakeehurst, on Union Branch, and above that point merges into the upper marshes. It reaches an altitude of 70 at Ridgeway Station, and the same elevation up Toms River 2 or 3 miles above White's Bridge. Here, too, it passes into the swampy tracts up stream.

From Toms River to Manasquan River.—Here the formation is much more extensive along the coast than farther south, covering a belt 5 or 6 miles wide west of Mantaloking and Pleasantville. Landward, its margin rises somewhat higher (40 to 50 feet) than farther south. It reaches an altitude of 70 feet or so about Farmingdale on the Manasquan, and 100 feet 8 miles farther up. Along this stream it is developed chiefly on the north side.

Between Manasquan River and Little Shrewsbury River.—North of Manasquan River the formation constitutes a belt a mile or so wide, bordered next the sea by modern beach deposits. Above Allenhurst, it covers much of the wide area below 40 to 45 feet. But here, as along Whale Pond Brook and the little stream just south of Elberon, the streams have cut through the young formation, exposing the Cretaceous beneath. In this stretch, therefore, the lower parts of the valley slopes, and the elevations which rise above 40 to 45 feet, as at Long Branch Village, are not covered by the formation.

Along Rumsons Road, from Sea Bright to Little Silver, the covering of recent deposits over Cretaceous is thin, especially at levels above 40 feet. About Little Silver, the area which may be mapped as having a cover of Cape May material is large, but the amount of material is small.

Along Parkers Creek, at the head of Little Shrewsbury River, a thin covering of sand, gravel, and loam over the Cretaceous, is to be correlated with the Cape May formation. It includes some eolian sand, and is chiefly on the south side of Parkers Creek and Wampum Brook. It extends up to Eatontown and beyond, and is mostly below the level of 40 feet; but some of the

land below this level is essentially bare Cretaceous. About Eatontown, the Cretaceous beneath the Cape May is sand, and easily shifted by the wind. Eolian sand is here much in evidence without being in great quantity. About Eatontown, the Cape May formation is ill defined, and not more than 3 or 4 feet thick, mostly sand.

About Oceanport the relations are about as at Eatontown. A few feet of sand, much of which looks as if it might be weathered Cretaceous, overlies sands known to be Cretaceous. A little gravel below the upper sand indicates that it is a surface accumulation rather than a weathered mantle.

From Oceanport to Long Branch, the Cape May formation covers much of the surface below 40 to 50 feet, though no contour line can be said to mark its limit; nor does it cover all the surface at lower levels. Some of the valleys below the 40-foot level appear to have been developed since its deposition, and have been cut through it into Cretaceous beds below. Along the shore, too, there is a margin of land made up of sand and gravel younger than the Cape May—the modern beach deposits.

The low but conspicuous little hills in the vicinity of Long Branch at elevations of 60 to 70 feet are of Cretaceous sand. Rising abruptly above their 20 to 30-foot surroundings, they seem like considerable elevations. Over the lowlands there are 3 to 6 feet of sand, derived chiefly from the Cretaceous of the vicinity. Some of it is eolian and underlain by a bit of gravel ranging from a trace to a few inches in thickness. Nowhere in the vicinity are there considerable beds of gravel referable to the Cape May formation. There are beds of sand and gravel 20 to 30 feet thick along the beach, but they are recent. The beach line is built against the mainland, instead of out from it, as farther north.

In the vicinity of West Long Branch, the following sections are fairly typical:

1. 3) 3 feet of compact fine gravel, sand and loam.
   2) 1 foot greenish-brown loam.
   1) 1 foot loose gravel and sand, of Cape May type.
   Cretaceous.

2. 2) 2 feet yellow-brown clay loam, with a few pebbles.
   1) 4 feet gravel and coarse sand, well stratified. Some cobble stones. Cretaceous.

West of Elberon, the Cape May cover has a thickness of 12 feet at least in places, but this is probably above its average. Such gravel as it contains is largely at its base, and as a formation it is ill defined. The whole situation here seems to suggest either (1) a filling by gravel wash behind a beach 30 to 40 feet high (now chiefly east of the railway between Long Branch and Manasquan), or (2) a gently sloping plain covered by wash against which a beach was built. The material back from the beach seems older than the beach itself, and this seems to favor the second alternative.

Half a mile west of Elberon, 6 to 10 feet of sand, gravel, and loam overlie the basal remnant of Miocene. The Cape May material is mostly well stratified, and not unlike that along the coast farther north, where terrace forms were well developed.

On the south side of Poplar Brook there are terraces at 30 to 40 feet which consist of glauconitic sand, 3 to 8 feet thick, underlain by a little gravel, and this by Cretaceous marl. Between Poplar Brook and Deal Brook the underlying terrane shifts from Cretaceous to Miocene, the base of the latter being about 20 feet above sea level along Deal Creek, near the coast. Between Poplar Brook and Deal Brook, the Cape May material is poorly defined in most places, as over most of the area between this point and Little Shrewsbury River.

About Edgemere there are about 4 to 6 feet of material which may be regarded as Cape May, overlying Eocene marl.

Asbury Park stands on the modern beach deposits. On the south shore of Deal Lake, the Eocene marl outcrops, and to the westward it appears at higher and higher levels. It is covered by scant deposits of gravel and sand, which thin westward as the surface of the marl rises.

At West Park, near the top of the 44-foot area, a remnant of Miocene appears, its base having an altitude of about 25 feet, and the surrounding lowland at the Cape May level is of this formation, thinly covered with sand and loam, not older than

the Cape May formation. In other words, the relations at Asbury Park are much the same as at Edgemere and South Elebron. The beach sand and gravel rest on a sloping surface of Eocene marl, the top of which is below sea level for half a mile or so back from the shore. These relations continue to Shark River.

The same relations hold in general from Shark River to Manasquan River. There is a belt a mile and a half wide next the shore, mostly below 30 feet. The shore-ward half of this belt is modern sand and gravel, the land-ward half a sloping surface of Miocene, covered by a thin mantle of sand and gravel of Cape May age, which thins westward.

Shrewsbury and Swimming Rivers.—The Cape May formation has some representation in all the principal tributaries of the Swimming River, and a larger development east of Red Bank, bordering the bay called Shrewsbury or Navesink River. Indeed it covers much of the peninsula between the Shrewsbury River, and the wider bay to the south called Little Shrewsbury River.

At the lower end of Swimming River the formation has an elevation of about 40 feet in the vicinity of Red Bank, but rises progressively up stream to 160 feet near the headwaters of some of the branches of Hop Brook, heading in the Beacon Hill region. Along Yellow Brook and Pine Brook, the other branches of Swimming River, it does not rise so high, obviously because these creeks do not head in such high land.

Between Oceanic and Red Bank there are more or less distinct terraces along the coast at levels ranging from 20 to 40 feet. These are composed of 10–20 feet of Cape May material over a Cretaceous bench. Red Bank stands on a terrace of this sort. There are similar terraces on the north side of Shrewsbury River, especially at the lower ends of tributary streams. In height and constitution these terraces are like those at Atlantic Highlands, Cliffwood, and Lawrence Harbor (see below), and doubtless are one with them in origin. Sections show well-stratified sand and gravel. These conditions suggest a stand of the land once 40 feet lower than now, at which time there was some accumula-

tions of sand and gravel just above the water, up to what is now 50 feet, more or less.

In the valley of Clay Pit Creek, there is a good deal of gravel referable to this formation, especially near the Shrewsbury River, where it is more than 30 feet deep in places. In the valley of the larger creek west of Clay Pit Creek there is a considerable body of gravel on the east side, and on the bank of the Shrewsbury at its lower end; but it does not take on a distinct terrace form at most places. Terraces are more distinct a mile and more up the valley, at altitudes ranging from 50 to 70 feet.

Due north of Red Bank there are distinct terraces at elevations of 20 to 30 feet, but they are composed of Cretaceous beds covered but thinly with younger sediments. Cape May sediments appear, however, at the lower ends of Poricy and Nut Swamp Brooks.

In contrast with the phenomena of the smaller streams, there are terraces up the valley of Swimming River and its main branches for many miles. They are low, composed wholly of Cape May sands and gravels in some places, while in others a thin coating of sediments of this age covers the local Cretaceous formation. The terraces rise progressively up stream, maintaining a height of 20 to 40 feet above the channel of the river.

Up Swimming River to the junction of Yellow Brook with Hop Brook, the formation has considerable development on both sides of the stream, forming low terraces or overspreading the lower slopes of the valley, and reaching elevations of 40 to 50 feet. Just below the mouth of Hop Brook, the thickness of the formation is as much as 20 feet on the north side of the stream. Below Phalanx, the terraces are clearly correlated with the 40-foot terraces about the coast, with which they are nearly continuous.

Hop Brook.—In the valley of Hop Brook, up to the junction of its several principal branches, the formation is disposed as in the valley of Swimming River, rising however to higher levels (70 feet), with indefinite upper limits. There are more than 20 feet of well stratified gravel and sand at some places, while in others the formation is represented by no more than a thin

coating over Cretaceous benches. In the valleys of the several streams which join to make Hop Brook, the formation is represented best along the streams from the north.

At and above the junction of the three principal branches of Hop Brook, the terrace material is abundant, and rises to 90 feet on the slopes. There is here some suggestion of terraces at different levels, but they are not persistent. Up the brook that has its source near Crawfords Corner, the deposits are almost continuous from Phalanx to the heads of the valleys, rising to elevations of 160 or 170 feet. The deposits are rarely 10 feet deep, but are so disposed on the sloping surface of the Cretaceous as to develop feeble terraces. The terrace form is distinct opposite the mouth of Willow Brook, and opposite and just south of Holmdel, where the altitude is 90 feet. The material is glauconitic sand and gravel, the latter containing much ironstone, which looks as if freshly worn. A mile northeast of Holmdel, just west of the 157-foot hill, 20 feet of the formation have been seen in temporary exposures, the material being loose sand and gravel. Comparable depths are shown at a few points farther north.

On the whole, the deposits of this valley are what might be expected along a stream heading in such high hills of loose material. They are not such as to demand a special epoch of deposition. It is to be noted that the terraces rise up the stream (30 feet at Phalanx to 170 at Crawfords Corner) at a rate which is harmonious with the gradient of the stream.

Willow Brook.—This branch of Hop Brook heads in the high hills about Beacon Hill, and has a high gradient down to its junction with Hop Brook. At the junction of Hop Brook with the brook from Crawfords Corner, the surface of the Cape May formation has an elevation of about 60 feet between the two creeks, and its base an elevation of about 50 feet. For 3 miles up stream, the right bank of Willow Creek has little Cape May material but along the left bank, the lower part of the slope is mantled with it. Near the stream, sands and gravels predominate, and back from the stream, loam.

The material of the terraces is best exposed northwest of Holmdel, where the brook forks. Between the forks, an exposure showed 4 feet of brownish loam, rather clayey, over 10 feet of glauconitic sand and gravel, well stratified. The 14 feet of material referable to the Cape May formation here is more than the average, but in kind it is similar to that seen at other points.

The above section is at an altitude of about 130 feet, and about 1½ miles from the headwaters of the creek. Farther up the valley corresponding deposits, except of coarser materials, are found up to 180 feet, and perhaps even to 230 feet. This material is clearly waste from the higher lands, temporarily lodged on its way to the sea. Much of it is of recent deposition.

In general the Cape May material along Willow Brook is on benches of Cretaceous strata 10 to 30 feet above the streams. The creek has cut down through the filling, and 10 to 30 feet into the Cretaceous below. The terraces indicate either a slightly lower stand of land when the filling took place, or a condition which favored more erosion than now, near the headwaters. The relations of the formation here are much as in other brooks hereabout, except that there is rather more material in this valley than in most of the others. The explanation of this difference is found in the higher lands in which the brook heads.

Yellow Brook.—The Cape May deposits along Yellow Brook are less considerable than those along Willow Brook, as already implied. The deposits are represented in the area between Hop Brook and Yellow Brook, and at intervals up the valley to Colts Neck; but they are thin in many places, even where distinct. Even where terraces are fairly distinct, they are not in all cases of Cape May material chiefly. No section showing more than 10 feet of this material has been seen on the north side of the valley, the thickest being east of north of Colts Neck. The formation does not appear to rise higher than 90 feet at Colts Neck.

On the south side of the brook, north of Scobeyville, there is a terrace at 50 to 60 feet, which shows the following section:

4) 5 feet eolian sand.
3) 8 feet gravel and sand, well stratified; ironstone conspicuous.
2) 1 foot glauconitic sand, with laminæ of clay.
1) 3 feet fine gravel and sand.

Up the creek which heads near Wickatunk, there is some Cape May material rising to nearly 170 feet at Wickatunk. At the lower end of the brook, the material runs up the slope to about 80 feet. For 1½ miles above the lower end of the brook, there are terraces at 80 to 90 feet, with 10 feet or less of sand and gravel. There is more of the Cape May gravel and sand on the north than on the south side of the valley, depths of 8 to 10 feet being seen at various points. The material is glauconitic.

Pine Brook.—Cape May gravel and sand are found up Pine Brook to a point 2 miles above Tinton Falls. At the lower end of the brook there is 20 to 30 feet of terrace material, at the 40- to 50-foot levels. Up to Tinton Falls and above, the deposits are mostly on the north side of the stream, where there are meager and indistinct terraces, ranging from 40 feet in elevation to slightly higher levels. Above Tinton Falls there are terraces at 50 feet, but the Cape May material is thin.

There is a good deal of eolian sand in the valley of Pine Brook, as on the area between Pine Brook and Hockhockson Brook.

Just west of Macedonia, in the vicinity of Pine Brook Station, there is an area from 70 to 85 feet in altitude, covered with 6 to 10 feet of glauconitic sand, largely eolian. Its source is probably the "Yellow" sand of the Cretaceous, a local phase of the Vincentown formation. Other areas of similar glauconitic sand are known in the vicinity, as between Colts Neck and Tinton Falls. The 90-foot areas east and west of Scobeyville, for example, are mantled with it. A bit of gravel occurs at the base of the sand in many places.

IN THE LOWER RARITAN DRAINAGE BASIN.

Manalapan and Matchaponix creeks.—Along Manalapan Creek the Cape May formation has some development up to the vicinity of Englishtown, but it occurs in patches only, now on one side of the stream and now on the other, down to Jamesburg. From Jamesburg down to Old Bridge it is widespread, but thin and low, mostly below 30 feet.

Most of Jamesburg stands on a terrace of this material. There is a distinct terrace east of the Upper Jamesburg depot, at the 60-foot level. The Cape May gravels and sands are deepest near the stream, and thin out back from it, as the surface of the Cretaceous rises. The material is such as Manalapan Creek could have gathered from its upper basin. The phenomena at Jamesburg and farther east suggest conditions which allowed much accumulation of sediment here at the 60-foot level in this epoch, while much less was being deposited farther down the valley. Between Helmetta and Old Bridge a thin bed of the formation covers a wide low tract at an elevation of 30 feet or so, but the amount of material is small, Cretaceous beds appearing at many points in the 20- to 30-foot flats. In general it may be said that most of the surface in this region below 40 feet is covered by a thin and somewhat discontinuous body of sand and gravel referable to this formation, though its age is not determinable with precision.

In the valley of Matchaponix Creek, the Cape May deposits extend up to Texas, and interruptedly beyond; but there is nowhere a deposit corresponding in quantity and height to that at Jamesburg.

The phenomena between Jamesburg and Old Bridge do not seem to be altogether in harmony with those at Jamesburg, if the Cape May formation is all the work of rivers. Has most of the formation below Jamesburg been removed by erosion? This seems hardly likely, in view of the great amount of erosion required, and in view of the low altitude, which would hardly have favored the removal of so much material as this hypothesis demands.

The phenomena between Spotswood and Old Bridge are continued east of Old Bridge, affecting most of the surface of the low area (below 45 feet or so) nearly to Brownstown. The formation also borders South River on the east, in a narrow belt down to the Raritan.

Lawrence Brook.—In the valley of Lawrence Brook the formation has little representation above Westons Mills, but it has some slight development between the lower end of the brook and the mouth of South River. The amount of material is small, and reaches levels of 60 feet (about the same as at Jamesburg), but does not cover all the surface up to this level. It is shown as well as anywhere on the island near the mouth of the brook, an island having a maximum altitude of 44 feet. Its top is covered with Cape May sand and gravel, though its basal part is Cretaceous. The Cape May material here contains no northern material, such as is found on the north side of the Raritan, and up the Raritan to Bound Brook. Traces of Cape May benches are to be found at various points up Lawrence Brook, but they are trifling both in extent and in amount of material. In this respect, Lawrence Book is in contrast with most of the streams of southern New Jersey. The absence or paucity of the late deposits in this valley probably is the result partly of lesser deposition at the outset, and partly of greater erosion since. The formations, the topography, and the situation of the basin of this brook with reference to glacial drainage, all contribute to this view. On the other hand, if the region were submerged to 60 feet, little deposition would need to have taken place in the narrow strait which would have occupied this valley.

Raritan River.—The remnants of glacial gravel below Bound Brook, up to altitudes of 60 feet or so, suggest that the lower part of the Raritan Valley was filled with sediment during the last glacial epoch, up to elevations corresponding with the filling of the Delaware; but this conclusion is not altogether decisive. If there was such filling, the deposits have been almost wholly carried away; there is even less glacial gravel down the Raritan than up the Millstone. There is also the question as to whether the valley was drowned to the level of 60 feet, allowing trans-

portation of glacially derived gravels along the shore of the narrow bay thus formed.

At the mouth of Mill Brook, on the north side of the river, there are terraces comparable to those at the mouth of Lawrence Brook on the south side, in both places at or near the 60-foot level. The terraces at the mouth of Mill Brook contain no glacial material brought down by the Raritan.

Below South River, the Cape May formation has some representation east of Sayreville, and thence along the bank of the river to South Amboy, being confined to levels below 40 to 50 feet. Well-defined terraces are wanting.

It is not demonstrable from the phenomena now presented by this valley, either that submergence did or did not affect this region in the last glacial epoch. It seems clear that glacial waters went from Bound Brook up the Millstone at that time, either as a river, or through a narrow strait. If the latter, they must have gone down the Raritan also, cutting off the southern part of the State from the northern by a narrow strait. The phenomena farther south do not seem to give this hypothesis firm support.

South shore of Raritan Bay.—The Cape May formation has little representation on the south shore of Raritan Bay from South Amboy to Keyport, though it appears in a few small areas, and in some places, as at Morgan, Lawrence Harbor and Cliffwood, in well-defined terraces, at elevations of 30 to 40 feet.

South and east of Keyport its development is more considerable. It extends up Matawan Creek, reaching an elevation of 50 feet, a mile above Matawan. It covers a considerable area east of Keyport, mostly below an elevation of 40 feet, and extends up the valley of Waycake Creek for 4 miles. It is mostly on the east side of the valley, and covers most of the lowland (below 40 feet) between Keansburg and Bedford. Farther east, it covers a belt from Atlantic Highlands across the peninsula by way of Navesink and Clay Pit creeks, to Shrewsbury River, rising to altitudes of 50 feet or so at its higher points.

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